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Operation and Maintenance Manual for Fabric Filters

PEI Associates, Inc., Cincinnati, OH

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Operation and Maintenance Manual for Fabric Filters

by

PEI Associates, Inc.
11499 Chester Road
Cincinnati, Ohio 45246

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EPA Project Officer
Louis S. Hovis
Gas Cleaning Division
Particulate Technology Branch

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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16. ABSTRACT

This manual presents a general description of fabric filter types and examines their applicability to varying gas stream conditions and particulate characteristics.

The purpose, goals, and role of performance monitoring are identified as a major element in an O&M program. Discussions focus on key performance indicators and their measurement and on instrumentation, data acquisition, and recordkeeping methods useful in optimizing fabric filter system performance.

The manual discusses the use of performance monitoring and other information to evaluate equipment performance, diagnose real or impending problems, and troubleshoot problem and malfunction causes. Tracking procedures and trends analysis methods that can be used to assess current or impending deterioration in performance are also discussed. Problem diagnosis and potential corrective measures are described. Guidelines are presented for general O&M practices and procedures for use in improving and sustaining fabric filter performance and reliability.

The manual presents methods and procedures for detailed inspections of fabric filter systems and their components. It provides step-by-step procedures and techniques for conducting external and internal inspections at both large and small fabric filter installations. Inspection during the pre-operational construction phase and the performance demonstration (baselining) period are also addressed.

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A review panel consisting of 34 members provided input throughout this project. They are listed below in alphabetical order:

Name	Affiliation
Charles A. Altin	Ebasco Services, Inc.
Ralph Altman	Electric Power Research Institute
William S. Becker	State and Territorial Air Pollution Program Administrator
Eli Bell	Texas Air Control Board
William S. Bellanger	U.S. EPA Region III
Robert Brown	Environmental Elements Co.
Steven Burgert	East Penn Manufacturing Co.
John M. Clouse	Colorado Department of Health
Jim Cummings	U.S. EPA Office of Policy Analysis
Duane Durst	U.S. EPA Region VII
Heinz Engelbrecht	Wheelabrator-Frye
David Ensor/David Coy	Research Triangle Institute
Kirk Foster	U.S. EPA Stationary Source Enforcement Division
F.W. Giaccone	U.S. EPA Region II
Wally Hadder	Virginia Electric Power Company
James Hambright	Pennsylvania Bureau of Air Quality Control
Norman Kulujian	U.S. EPA Center for Environmental Research Information

Name	Affiliation
John Lytle	Tennessee Valley Authority
Richard McRanie	Southern Company Services
Grady Nichols	Southern Research Institute
Sid Orem	Industrial Gas Cleaning Institute
John Paul	Montgomery County, Ohio Regional Air Pollution Control Agency
Charles Pratt	U.S. EPA - Training
Richard Renninger	National Crushed Stone Association
John Richards	Richards Engineering
A.C. Schneeberger	Portland Cement Association
Eugene J. Sciassia	Erie County, New York Department of Environment and Planning
Don Shephard	Virginia Air Pollution Control Board
Lon Torrez	U.S. EPA Region V
William Voshell	U.S. EPA Region IV
Glenn Wood	Weyerhauser Corp.
Howard Wright	U.S. EPA Stationary Source Enforcement Division
Earl Young	American Iron and Steel Institute

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SECTION 1
INTRODUCTION

The success of an air pollution abatement program ultimately depends upon effective operation and maintenance (O&M) of the installed air pollution control equipment. Regardless of how well an air pollution control system is designed, poor O&M will lead to the deterioration of its various components and a resulting decrease in its particulate removal efficiency. This is particularly true with fabric filters; if not corrected, a small problem like a pinhole leak in a bag can result in the failure of the surrounding bags within a short time.

Effective O&M also affects equipment reliability, on-line availability, continuing regulatory compliance, and regulatory agency/source relations. Lack of timely and proper O&M leads to a gradual deterioration in the equipment, which in turn increases the probability of equipment failure and decreases both the reliability and on-line availability of the equipment. These latter two items can decrease plant productivity if process operations are forced to be curtailed or shut down to minimize emissions during air pollution control equipment outages. Frequent violations of emission limits can result in more inspections, potential fines for noncompliance, and in some cases, mandatory shutdown until emission problems are solved.

This manual focuses on the operation and maintenance of typical fabric filters. The overview presented in Section 2 summarizes the available information on fabric filter theory and design in sufficient detail to provide a basic background for the O&M portions of the manual. Numerous documents are available if the reader desires a more rigorous treatment of fabric filter theory and design.

The manual is designed to be an educational tool for plant and EPA personnel, not an enforcement tool. No attempt is made to tell plant personnel how to operate a plant; rather, the manual provides cause-effect relationships to assist in the prevention or location of problems. Actual plant experience and examples are used to demonstrate or illustrate certain points. The manual will not only serve as a handy reference regarding fabric filter O&M, but also provide the necessary information to assist plant personnel in the preparation of their own site-specific O&M manual.

1.1 SCOPE AND CONTENT

Section 2 of the manual presents an overview of fabric filter theory and design in sufficient detail to provide a background for the other sections in the manual. Although this section does not provide "textbook" coverage of fabric filter theory and principles (such information is readily available in the technical literature), it does draw attention to some new information or recent developments that may be useful in improving fabric filter O&M. This section also presents a general description of fabric filter types and examines their applicability to varying gas stream conditions and particulate characteristics.

Section 3 presents the purpose, goals, and role of performance monitoring as a major element in an O&M program. Discussions will focus on key performance indicators and their measurement and on instrumentation, data acquisition, and recordkeeping methods useful in optimizing fabric filter system performance.

Section 4 discusses the use of performance monitoring and other information to evaluate equipment performance, diagnose real or impending problems, and troubleshoot problem and malfunction causes. Tracking procedures and trends analysis methods that can be used to assess current or impending deterioration in performance are also discussed. Problem diagnosis and potential corrective measures are described.

Section 5 presents guidelines for general O&M practices and procedures for use in improving and sustaining fabric filter performance and reliability. General guidance, rather than specific instructions, is given because of the unique nature of these control device systems and of the process streams they serve. The intent of this section is to prescribe the basic elements of good operating practice and preventive maintenance programs that can be used as the basis and framework for tailored, installation-specific programs.

Section 6 presents methods and procedures for detailed inspections of fabric filter systems and their components. It provides step-by-step procedures and techniques for conducting external and internal inspections at both large and small fabric filter installations. Inspection during the preoperational construction phase and the performance demonstration (baselining) period are also addressed. Safety considerations are emphasized and any special precautionary measures at major source installations are stated. The portable instrumentation and safety equipment needed during inspection are listed, and example inspection checklists are provided.

Section 7 summarizes important items that an adequate O&M plan should include. Different plans are suggested for small vs. large fabric filter operations. The format of this section consists of an annotated outline of the key items that should be included in a model O&M plan.

Appendix A shows examples of fabric filter O&M forms. Appendix B summarizes the development and status of fabric filter application to utility boilers. Although this is an application that is still being developed, many of the initial problems have already been solved. A glossary of terminology is also presented.

1.2 INTENDED USE OF MANUAL

The intent of this manual is to present O&M principles and procedures to supplement plant-specific O&M techniques and strategies. An underlying objective is to improve air quality by providing technical guidance that will upgrade the reliability and performance of fabric filters.

The intended audience is the plant environmental engineer, plant O&M personnel, and EPA field personnel. The contents are slanted toward the concerns of the plant environmental engineer, however, who with the assistance of his/her staff is responsible for long-term control strategies, O&M plans, preparation of bid specifications, and performance trends analyses. The document also presents information to enable plant O&M personnel to recognize potential problem areas as well as existing problems, their underlying causes, and their solutions. The information provided should help EPA field personnel to determine if the fabric filter is operating within the applicable regulations, to judge the effectiveness of the plant's O&M program, and to assess the causes of poor fabric filter performance.

The plant environmental engineer will generally have overall responsibility for the proper O&M of the fabric filter, for a wide range of trends analyses related to performance of the fabric filter, and for background information during the preparation of bid specifications. [illegible]is manual does not attempt to replace the step-by-step O&M manuals prep[illegible] by fabric filter vendors or documents developed by the plant for a sit[illegible]cific application. Neither does it directly address the development of bid specifications. It does, however, attempt to provide sufficient detail to enable the plant environmental engineer to evaluate the plant's present O&M program and determine if and where improvements are needed. The examples presented throughout the text can be used to become aware of potential problems that can occur that the engineer may not have experienced as yet. The descriptions, general procedures, and analytical techniques presented can assist the plant environmental engineer and the central engineering staff in developing bid specifications for purchase of a fabric filter that will facilitate O&M as well as performance evaluations and trends analyses.

Plant O&M personnel should not use this manual for specific instructions on startup and shutdown procedures. Such instructions should be provided by the equipment manufacturer, and minor modifications should be made by plant personnel to fit site-specific needs. This manual presents general operating guidelines that can be used as a background document for determining the completeness of the plant's fabric filter operating manual, preventive and corrective maintenance procedures, and troubleshooting and inspection procedures.

For EPA field personnel, the manual provides guidelines for a detailed field inspection of fabric filter systems. Emphasis is on the inspection methodology for evaluating both equipment and performance. Discussions do not include topics covered in detail elsewhere (e.g., source testing and opacity readings).

Other user groups will find the manual provides useful general information on fabric filter O&M and problems encountered in a wide variety of fabric filter applications. The manual clearly shows that actual fabric filter O&M and performance often differ greatly from theorized O&M and performance.

SECTION 2

OVERVIEW OF FABRIC FILTER THEORY, DESIGN, AND O&M CONSIDERATIONS

The general descriptions of the basic theory and principles of filtration, fabric filter systems, and O&M considerations presented in this section are intended only to provide a background for the remainder of the manual. Detailed information is readily available in various textbooks and in the proceedings of pertinent seminars and conferences.

2.1 BASIC THEORY AND PRINCIPLES OF FILTRATION

An understanding of the basic particle collection mechanisms and the factors that affect fabric filtration are necessary for any evaluation of parameter monitoring data for the establishment of optimum O&M procedures. It is important in the analysis of the cause-effect relationships between variations in operating parameters and operating conditions and fabric filter performance.

2.1.1 Particle Capture Mechanisms

A single fiber can be used to describe the various capture mechanisms of a fabric filter. As shown in Figure 2-1, the five basic mechanisms by which particulate can be collected by a single fiber are 1) inertial impaction, 2) Brownian diffusion, 3) direct interception, 4) electrostatic attraction, and 5) gravitational settling.

These collection mechanisms, plus sieving, also apply to a fabric with a dust cake, such as would be encountered under typical operating conditions. Inertial impaction is the dominant collection mechanism within the dust cake. The forward motion of the particles results in impaction on fibers or on already deposited particles.[1,2] Although impaction increases with higher gas velocities, these higher velocities reduce the effectiveness of Brownian

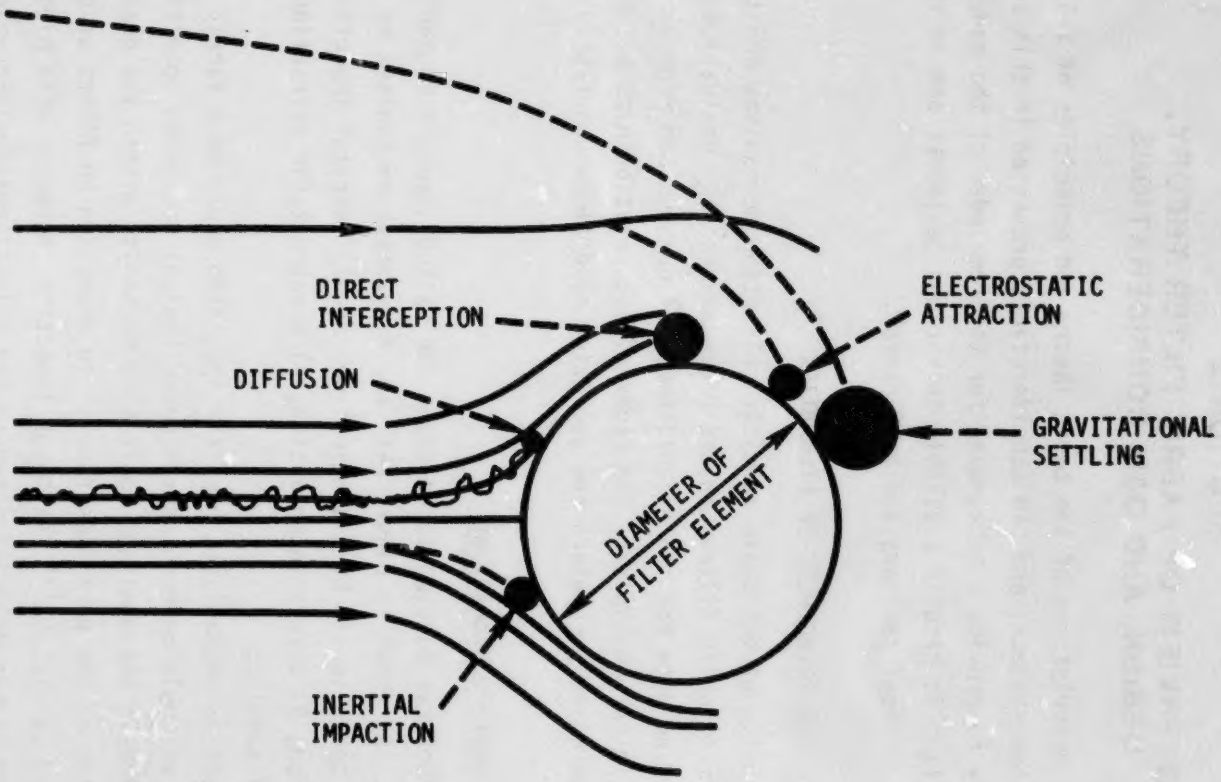


Figure 2-1. Initial mechanisms of fabric filtration.
Reprinted with permission from Industrial Air Pollution Control Equipment for Particulates by L. Theodore and A. J. Buonicore, Copyright CRC Press, Inc. Boca Raton, Florida. 1976.

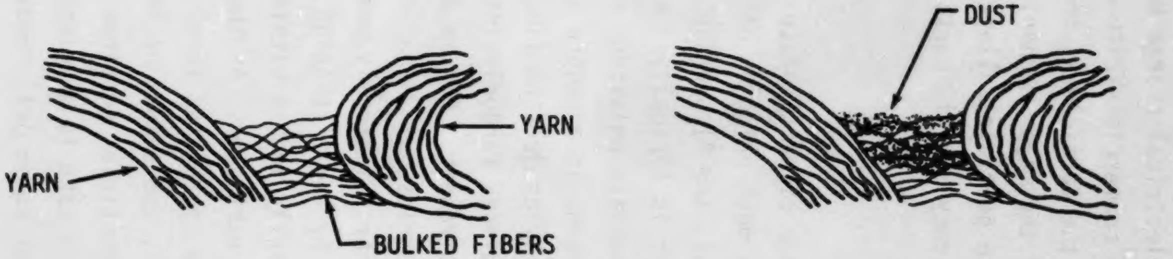
diffusion. Increasing the fabric and dust cake porosity by use of a less dense fabric or more frequent cleaning also reduces diffusional deposition.[3] Except at low gas velocities, gravity settling of particles as a method of collection is usually assumed to be negligible.[1,3,4] Electrostatic forces may affect collection because of the difference in electrical charge between the particles and the filter; however, the impact on commercial-scale equipment is not fully understood.[5] Sieving occurs when the particle is too large to pass through the fabric matrix. It is not one of the major mechanisms for collecting particulate. The combination of all these particle collection mechanisms results in high-efficiency removal efficiency for all particle sizes.

2.1.2 Dust Accumulation on Fabrics

The fabric filtration process or the accumulation of particulate on a new fabric surface occurs in three phases: 1) early dust bridging of the fabric substrate, 2) subsurface dust cake development, and 3) surface dust cake development. The fabric used in a fabric filter is typically a woven or felted material, which forms the base on which particulate emissions are collected. Woven fabrics consist of parallel rows of yarns in a square array. The open spaces between adjacent yarns are occupied by projecting fibers called fibrils. Felted fabrics are constructed of close, randomly intertwined fibers that are compacted to provide fabric strength. Figure 2-2 depicts this particle accumulation on woven glass fabrics.

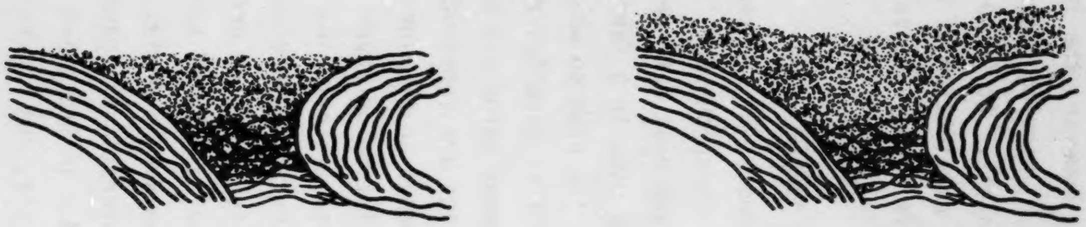
In the first phase, particles entering a new fabric initially contact the individual fibers and fibrils and are collected by the filtration mechanisms. These deposited particles, which are essentially lodged within the fabric structure, promote the capture of additional particles. As these particles build up during the second phase, particle aggregates form, bridging of the interweave and interstitial spaces occurs, and a more or less continuous deposit is formed. In the third phase, particles continue to collect on the previous deposit, and the surface dust cake is developed.

The cleaning cycle (via shaking, reverse air, or pulse jet) removes some of the surface cake. After a few cleaning cycles, theoretically, a steady-state dust cake should be formed, which will remain until the bag is damaged, replaced, or washed. Actually, however, the dust cake can vary significantly



UNUSED FABRIC

EARLY DUST BRIDGING OF FIBER SUBSTRATE



SUB SURFACE DUST CAKE DEVELOPMENT

SURFACE DUST CAKE DEVELOPMENT

Figure 2-2. Dust accumulation on woven glass fabrics.[10]

from cycle to cycle, particularly in severe applications such as utility boilers or metallurgical processes. This remaining cake forms a base for the collection of particles when the bag is put back on line after cleaning.

2.1.3 Gas Stream Factors That Affect Fabric Filter Design and Operation

A complete characterization of the effluent gas stream is important in the design and operation of a fabric filter system. It should include the gas flow rate; minimum and maximum gas temperatures; acid dew point; moisture content; presence of large particulate matter; presence of sticky particulate matter; particulate mass loading; chemical, adhesion, and abrasion properties of the particulate; and presence of potentially explosive gases or particulate matter. These data can be used to design a collector with the required degree of control or to optimize the operation of an existing fabric filter, as illustrated by the following examples:

1) The size of a fabric filter system is determined by the gas volume to be filtered, the air-to-cloth (A/C) ratio, and the pressure drop at which the filter can be operated given the fabric type, dust cake properties, and cleaning method. The area of fabric surface is determined by multiplying the total gas flow by the selected A/C ratio.

2) Penetration is related to the effective A/C ratio in the system, particularly if the A/C ratio is outside the optimum range for the specific application and type of fabric filter (see Section 2.2).[9,10] Therefore, the lowest possible face velocity consistent with economic constraints should be specified during the design phase. This parameter should also be considered in the operation of an existing fabric filter, if process flow rates increase significantly or additional sources are added.

3) Variations in gas stream temperature over time affect the operation and design of a fabric filter. The temperature of gases emitted from industrial processes may vary more than several hundred degrees within short periods of time. They may fall below the gas moisture and acid dew points or they may exceed the maximum that the fabric will tolerate. The temperature extremes must be determined before the filter fabric is selected and during evaluation of fabric filter performance.

4) The particle size distribution of the dust must be considered in the design and operation of the collector. Particle size distribution affects both the porosity of the dust cake and abrasion of the

fabric. The presence of fine particles in the gas stream can create a very compact dust cake and increase the static pressure drop through the cake.[11] These fine particles can also cause fabric bleeding if pulled through the fabric. The presence of large abrasive particles can reduce bag life and may necessitate the use of a precleaner or gas distribution devices in the collection system.

5) Moisture content and acid dew point are important gas composition factors. Operating a fabric filter at close to the acid dew point introduces substantial risk of corrosion, especially in localized spots close to hatches, in dead air pockets, in hoppers, or in areas adjacent to heat sinks, such as external supports.[12,13] Allowing the operating temperature to drop below the water and/or acid dew point, either during startup or at normal operation, will usually cause blinding of the bags. Acids or alkali materials can also weaken the fabric and shorten their useful life. Trace components, such as fluorine, also can attack certain fabrics.

2.1.4 Fabric Filter Models

Fabric filter models have been developed to predict performance with various operating and design parameters.[14] The greatest drawbacks to fabric filter models are their inability to account for real-world conditions, such as acid dewpoint excursions, the rate of formation of pinhole leaks or bag tears, and the effect of poor construction or maintenance. Modeling also requires site-specific information that is not easily obtained, such as the K factor (i.e., the specific resistance of the dust cake in inches water column per pound of dust per square foot of filter area per feet per minute of filtering velocity). In this section, a model developed by GCA Corporation[15] for the U.S. Environmental Protection Agency and applicable to coal-fired boilers is discussed briefly to show the typical variables that are included in a fabric filter model. Again, although none of the available fabric filter models is very useful in the evaluation of the effect of O&M practices on fabric filter efficiency, they can be used to some extent to evaluate the effect of some design parameters on the theoretical efficiency of the unit.

The GCA model[14] predicts the ability of fabric filters to clean coal-fired boiler flue gases. This model addresses filters having either mechanical or reverse-air cleaning mechanisms. It provides estimates of average and point values for penetration and mass effluent concentration for a selected set of operating parameters and dust/fabric specifications. The model expresses penetration or outlet concentration as a function of the following parameters:

$$P_n \text{ or } C_o = f\,(\Phi, C_i, W, F, C_R)$$

where P_n = penetration
C_o = outlet concentration
Φ = a parameter characterizing the dust/fabric combination of interest
C_i = inlet concentration (constant)
C_R = residual concentration
W = fabric dust loading
F = face velocity (determined by the air-to-cloth ratio)

To determine the parameter that influences fabric filter efficiency for a specific process, one can investigate each of the parameters individually. According to the model, face velocity is the design parameter with the greatest impact on penetration. Under actual field conditions, however, other factors may have a much more significant impact on fabric filter efficiency.

2.1.5 Fabric Filter Applications

The two fundamental applications of fabric filters are for nuisance dust control and for process control. These applications are discussed briefly below.

2.1.5.1 Nuisance Dust Control Applications--

Storage silos, woodworking shops, and materials transfer are examples of the types of operations where fabric filters would be used to control dust in the air. In many cases, low volumes of air are handled, and continuous on-line cleaning, long-life fabrics, corrosion, and other factors are usually not considerations in their design and operation.

2.1.5.2 Manufacturing Process Applications--

Fabric filter systems used to clean the exhaust from major processes may be required to operate 24 hours a day, 365 days a year. The exhaust streams may contain large high-temperature gas volumes, highly abrasive materials, submicron particles, and corrosive agents. In some cases, the process fabric filter may be critical to the plant's continued operation. In an asphalt plant, for example, if the fabric filter is not operating properly, the plant may not be able to achieve adequate production rates.[15]

If toxic substances are present in the gas stream, operation of the fabric filter is critical to the well-being of the workers and the general public (e.g., in a plant where lead oxide is generated). For these reasons, more sophisticated monitoring equipment (such as temperature and pressure gages at an inside monitoring station rather than outside) is used to monitor the performance of these units, and they generally represent a higher investment than fugitive dust collectors. Fabric filters controlling processes are stressed in this manual because of the wide variation in operating conditions to which they are exposed and the importance of troubleshooting and regular maintenance for efficient operation.

2.2 FABRIC FILTER SYSTEMS

Although the basic particulate collection mechanisms are the same for all fabric filters and gas stream factors affecting their performance are relatively similar, the equipment itself and fabrics used in fabric filter systems vary widely by vendor and application. Some of these variations are necessary to meet various performance capability demands and physical characteristics; others are the products of individual contributions of numerous equipment and fabric vendors.

Although fabric filters can be classified in a number of ways, the most common way is by their method of fabric cleaning: shaker, reverse-air, and pulse-jet.

2.2.1 Shaker-Type Fabric Filters

A conventional shaker-type fabric filter is shown in Figure 2-3. Particulate-laden gas enters below the tube sheet and passes from the inside bag surface to the outside surface. At regular intervals a portion of the dust cake is removed by manual shaking (small systems) or mechanical shaking

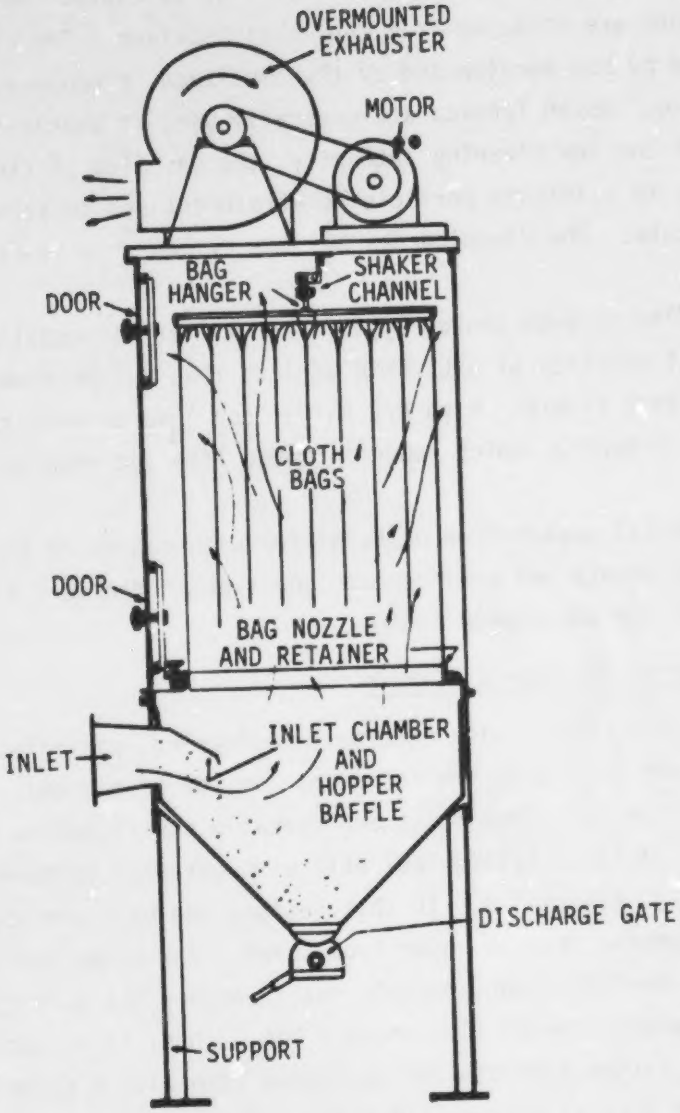


Figure 2-3. Small shaker-type fabric filter (Reprinted with permission from Flakt, Inc.).

(larger systems). Mechanical shaking of the filter fabric is normally accomplished by rapid horizontal motion induced by a mechanical shaker bar attached at the top of the bag. The shaking creates a standing wave in the bag and causes flexing of the fabric. The flexing causes the dust cake to crack, and portions are released from the fabric surface. The cleaning intensity is controlled by bag tension and by the amplitude, frequency, and duration of the shaking. Woven fabrics are generally used in shaker-type collectors; and because of the low cleaning intensity, the gas flow is stopped before cleaning begins to eliminate particle reentrainment and to allow the release of the dust cake. The cleaning may be done by bag, row, section, or compartment.

Gas flow through shaker-type fabric filters is usually limited to a low superficial velocity or A/C ratio of less than 3 ft/min and a typical range of from 1 to 2 ft/min. High A/C values can lead to excessive particle penetration or blinding, which reduces fabric life and results in high pressure drop.

Mechanical shaker-type units differ with regard to the shaker assembly design, bag length and arrangement, and type of fabric. All sizes of control systems can use the shaker design.

2.2.2 Reverse-Air Fabric Filters

In fabric filters with reverse-air cleaning, particles can be collected on a dust cake on either the inside or outside of the bag. Fabrics may be either woven or felt, but felts are normally restricted to external surface collection. A small cylindrical unit with external surface filtering is illustrated in Figure 2-4. In this design, the bags are arranged radially and are suspended from an upper tube sheet. The inner and outer row of reverse-air manifolds continuously rotate around the unit and use a dampering system to induce reverse flow in each bag. Thus, it is not necessary to isolate the entire baghouse for dust-cake removal. A somewhat larger and perhaps more typical reverse air filter is shown in Figure 2-5.

Regardless of design differences, the principle is the same. Cleaning is accomplished by reversal of the gas flow through the filter media. The change in direction causes the surface contour of the filter surface to change (relax) and promotes dust-cake cracking. The flow of gas through the

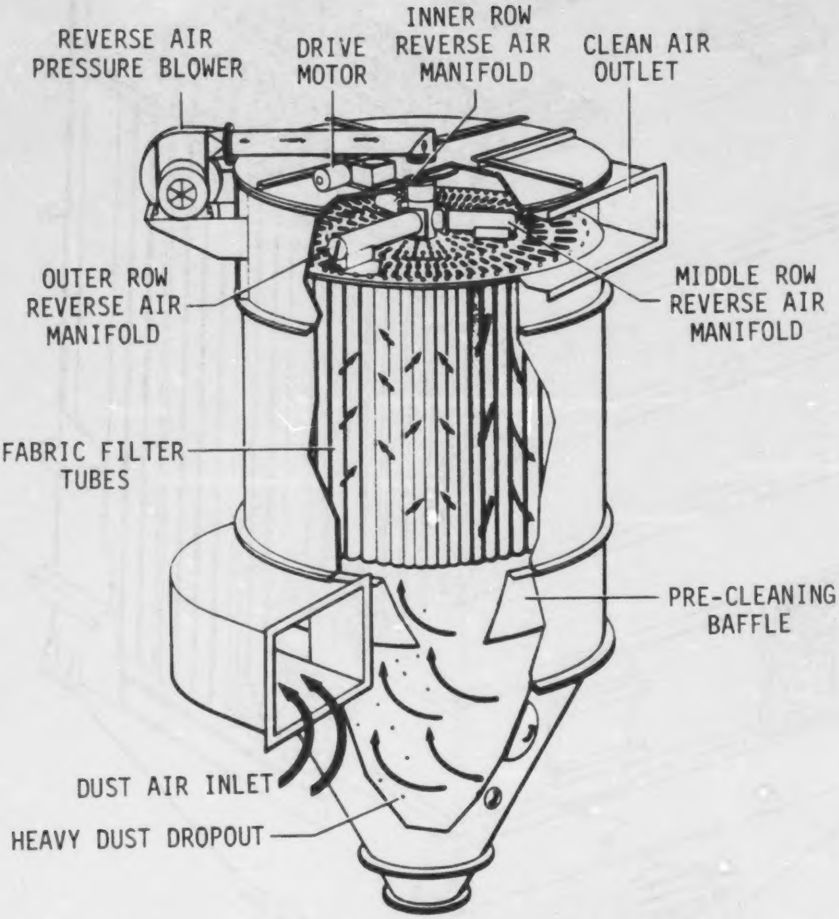

REVERSE AIR PRESSURE BLOWER
DRIVE MOTOR
INNER ROW REVERSE AIR MANIFOLD
CLEAN AIR OUTLET
OUTER ROW REVERSE AIR MANIFOLD
MIDDLE ROW REVERSE AIR MANIFOLD
FABRIC FILTER TUBES
PRE-CLEANING BAFFLE
DUST AIR INLET
HEAVY DUST DROPOUT

Figure 2-4. Example of a small cylindrical reverse-air fabric filter design (Courtesy of Carter-Day Company).

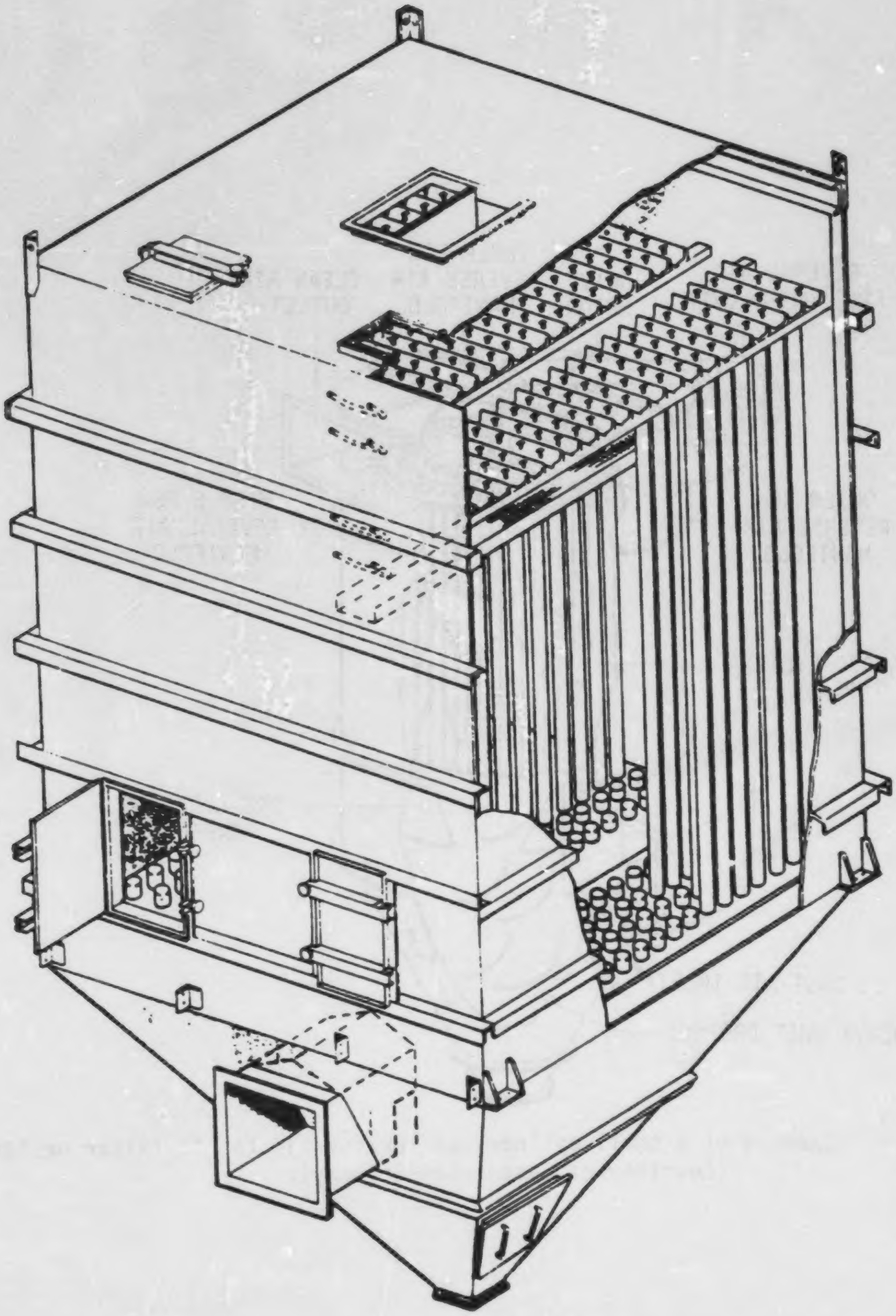


Figure 2-5. An example of a large reverse-air fabric filter (Courtesy of MikroPul Corporation).

fabric assists in removal of the cake. The reverse flow may be supplied by cleaned exhaust gases or by ambient air introduced by a secondary fan.

In filters with inside bag collection, cleaning is done with compartments isolated. The filter bags may require anticollapse rings to prevent closure of the tube and dust bridging.

Reverse-air filters are usually limited to A/C ratios of less than 3 ft/min, and a range of about 1 to 2.5 ft/min. In general, the appropriate A/C ratio for a reverse-air unit should be about one-third lower than for a similar shaker-type unit application.*

2.2.3 Pulse-Jet Fabric Filters

In pulse-jet fabric filters, filtering takes place on exterior bag surfaces. A small pulse-jet fabric filter is illustrated in Figure 2-6. The bags, supported by inner retainers (usually called cages), are suspended from a tube sheet, an upper cell plate. Compressed air for cleaning is supplied through a manifold-solenoid assembly into blow pipes. Venturis are mounted in the bag entry area to improve the pulse-jet effect and to protect the top part of the bag. The diffuser is placed at the gas inlet to prevent large particles from abrading lower portions of the bag.

During cleaning, a brief (generally less than 0.2-second) pulse of compressed air injected into the top of the bag creates a traveling wave in the fabric, which shatters the cake and throws it from the surface of the fabric. The dominant cleaning mechanism in a pulse-jet unit is fabric flexing. Felted fabrics are normally used, and the cleaning intensity (energy) is high. The cleaning usually proceeds by rows, and all bags in a row are cleaned simultaneously. The compressed-air pulse, which is delivered at 80 to 120 psi, results in local stoppage of the gas flow. The cleaning intensity is a function of compressed-air pressure. Pulse-jet units can operate at substantially higher A/C ratios than the previously discussed fabric filters because of their higher cleaning intensity. Typical ratios range from 5 to 10 ft^3/ft^2-min.

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* Correspondence between Wheelabrator-Frye, Inc., and PEI Associates, Inc., February 1, 1985.

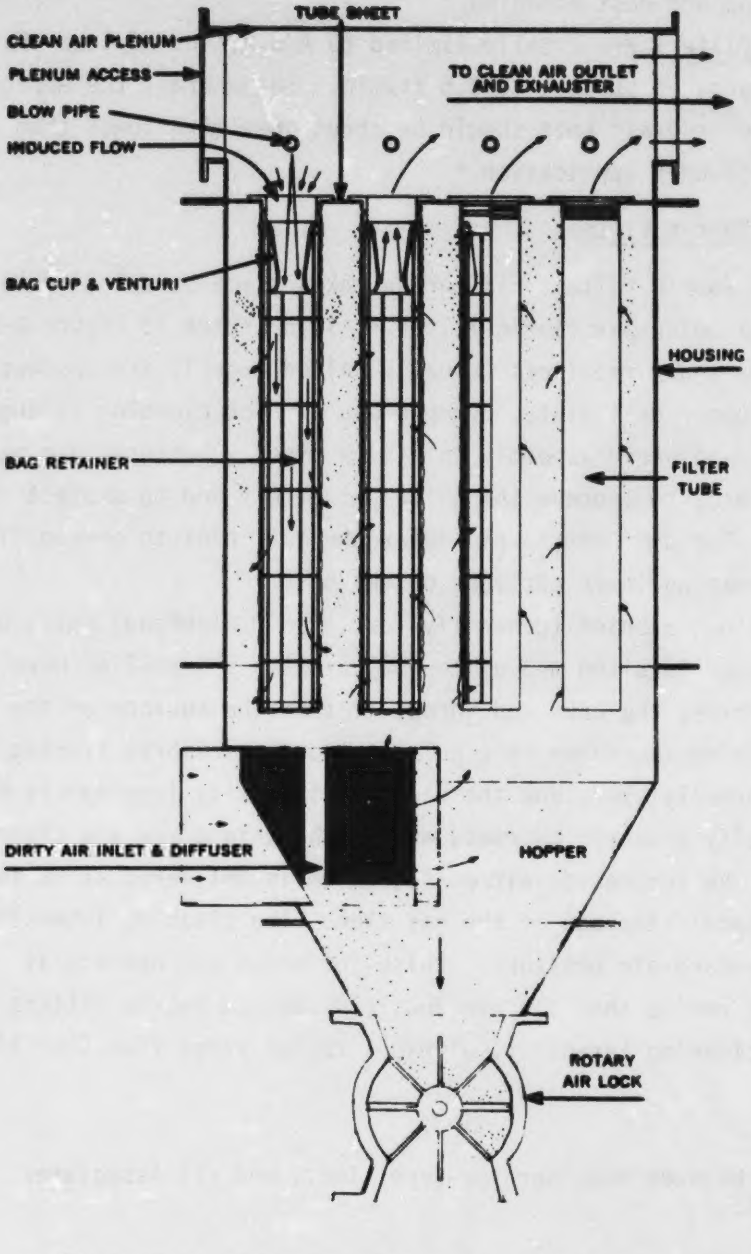


Figure 2-6. Example of a small pulse-jet fabric filter (Courtesy of George A. Rolfes Company).

The plenum pulse cleaning method is a variation of the pulse-jet cleaning mechanism; in this method, an entire section of bags is pulsed with compressed air from the clean air plenum.

2.2.4 Other Designs and Modifications

2.2.4.1 Positive-Pressure Vs. Negative-Pressure Units--

Fabric filters can be constructed either as a positive-pressure unit with the fan upstream of the fabric filter or as a negative-pressure unit with the fan downstream of the unit.

The use of a positive-pressure fabric filter eliminates the need for ductwork and a stack downstream of the unit, which reduces requirements for space and other materials but makes monitoring more difficult. Because positive-pressure units are generally not exposed to as high a static pressure as negative-pressure units, housing can sometimes be constructed of a bolted light-gauge material.[15] Any leaks from the fabric filter will enter the surrounding air, which eliminates the potential cooling effects of undesirable dilution air, but increases the risk of fugitive emissions from the unit. Positive-pressure units are frequently used to control arc furnaces, canopy exhausts, ferroalloy furnaces, and BOF reladling fumes.[16]

In negative-pressure units, the fan is located on the clean side of the filter, where it is subject to less wear from dust abrasion. The fabric filter housing must be gas-tight, as any leaks will draw air in from the outside. This outside air will normally cool the gas stream; and it could reduce the gas temperature below the dew point, which would cause condensation on the inside of the unit. In some processes, introduction of outside air increases the risk of fire and/or explosion. On the other hand, leaks will not result in fugitive emissions because ambient air is drawn into the unit. Negative-pressure units are generally used on coal-fired boilers, cement kilns, rock dryers, carbon black reactors/dryers, and nonferrous smelting furnaces.[16]

2.2.4.2 Fabric Filter Control of Sulfur Dioxide--

Some fabric filters used to control boilers are designed or modified to collect sulfur dioxide (SO_2) with a dry SO_2-collection system. The two basic methods of dry SO_2 removal are 1) dry injection and 2) spray drying. The first method consists of injecting a sodium compound (nahcolite) as a powder into the flue gas upstream of the fabric filter. The dry sorbent collects on the bags, and the SO_2 is removed, both in the suspended state and when the gases pass through the cake that has built up on the bags.[17] In the spray drying technique, an atomized alkaline solution or slurry (lime) is injected into the flue gas. As the alkaline material evaporates to dryness, it reacts with the SO_x and HCl in the flue gas.[18] The resultant reaction products are collected, usually along with the fly ash in the fabric filter, and disposed of as a dry waste.

The primary advantages of both dry removal systems are the lower capital cost associated with the simultaneous removal of SO_2 and particulate in the system, greater availability of the system because of its simplicity, and lower energy and water consumption than with wet scrubbers. Spray drying has an additional advantage in that it can be used in conjunction with either fabric filters or electrostatic precipitators.

The main disadvantages of spray drying are that high removal efficiencies are more difficult to obtain, a highly reactive (i.e., nonlimestone) absorbent must be used, and the spent sorbent cannot be easily disposed of.[17]

2.2.5 Recent Developments and Trends

Many of the continuing efforts to develop new techniques, technologies, and applications for fabric filters are not within the scope of this report because they are either in the early stages of development or the topic is of limited interest. These topics include:

- Electrostatically enhanced filtration
- Wet and granular filters
- Grounded bags in coal mill installations
- Counterweight bag tensioner
- Stainless steel and other exotic materials for bags.

Further information on these topics can be obtained by reviewing specialty conference proceedings and periodical articles.

The relatively new products that are described briefly include the Staclean diffuser and sonic enhancement of bag cleaning. The Staclean diffuser is designed to provide a better distribution of the cleaning pulse in pulse-jet fabric filters. This perforated tube, which fits inside the bag cage, reportedly prevents the full force of the pulse from acting on the top portion of the bag and allows more of the pulsed-air energy to reach the bottom of the bag. The expected result is more uniform cleaning of the bag and longer bag life.[19]

The Electric Power Research Institute (EPRI) and the Public Service Co. of Colorado (PSC) have tested the effectiveness of sonic energy enhancement in removing accumulated dust from the bags of a reverse-air filter and keeping the pressure drop down.[20] In this method, horns sound during the reverse-air cleaning cycle to help dislodge the filter cake. Both EPRI and PSC have had success with this technique; pressure drop has decreased as much as 40 to 50 percent.[20] Further studies are being conducted by EPRI to determine the impact of different horn frequencies, locations, timing, and duration.[20] All installations to date have been retrofitted. The effectiveness of this technique in preventing excessive residual dust cake buildup on clean bags has not yet been demonstrated.

2.3 SYSTEM COMPONENTS

2.3.1 Fabric

Filter fabrics commonly used in operating facilities are either felted or woven. Felt is a genuine filter medium and collects particulates more efficiently at comparable gas velocities; however, it is also more expensive. Felted fabrics are composed of randomly oriented fibers and are relatively thick. The thickness provides maximum particle impingement, but it also increases the static pressure drop. Felted fabrics are normally used in pulse-type units and are operated at high A/C ratios.

Woven fabrics are generally used in shaker and reverse-air filter systems and are operated at relatively low A/C ratios. Woven fabric is made up of filament or staple (spun) yarns in a variety of weaves with various spacings between the yarns. The finish is specifically designed to retain or shed filter cake, depending on the application. Figure 2-7 shows seven of the most common weave patterns. Plain weave has the lowest initial cost, the least porosity, and the greatest particle retention; however, it also has the

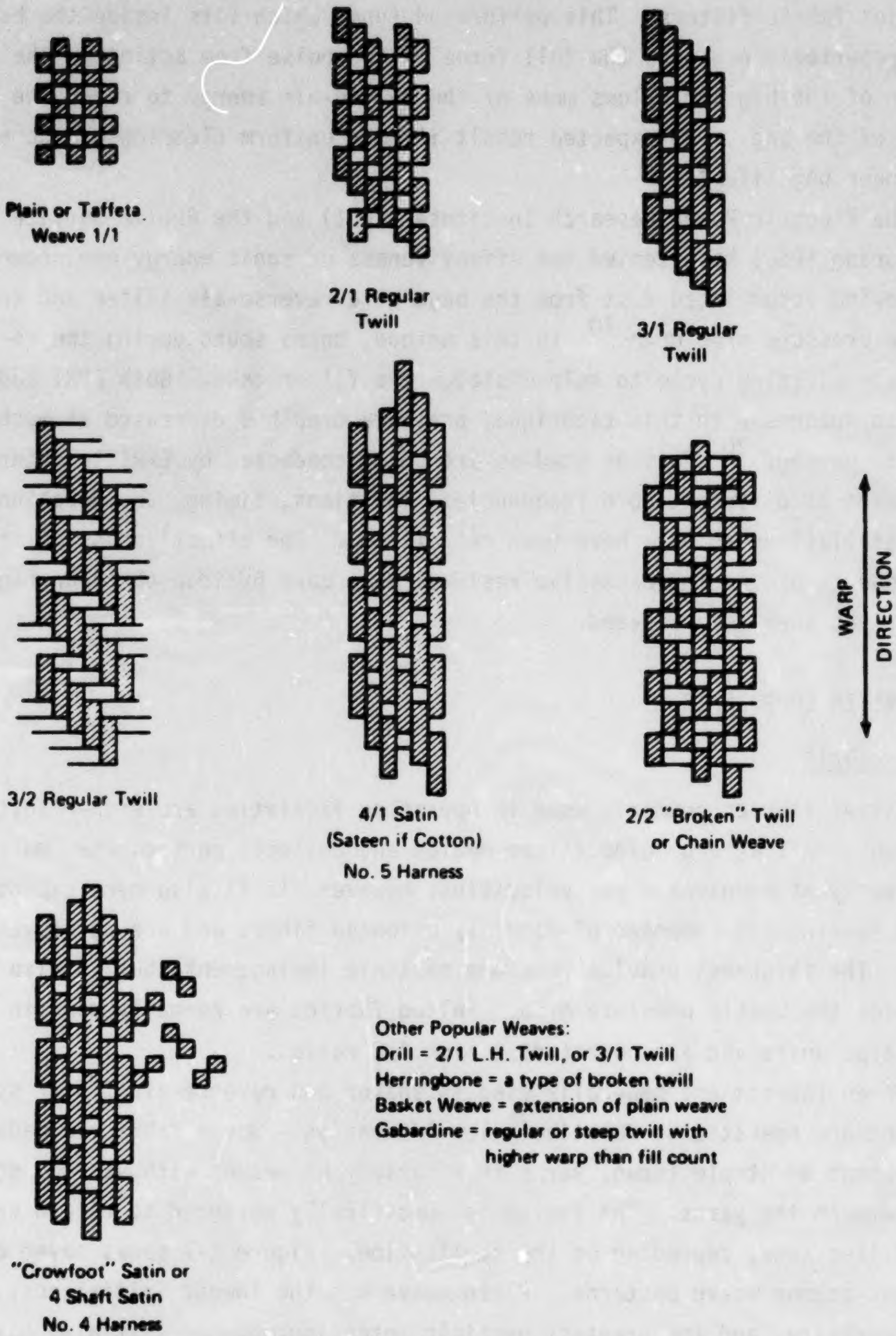


Figure 2-7. Typical fabric weaves (reprinted by permission: Industrial Gas Cleaning Institute).

greatest potential for blinding. Twill weave has medium retention and blinding characteristics and has reasonable permeability; it also exhibits the best resistance to abrasion. Sateen weave has the lowest particle retention, is easiest to clean of accumulated dust, and has the lowest potential for blinding. The permeability of woven fabrics depends on the type of fiber, the tightness of the twist, the size of yarn, the type of weave (geometric pattern), the tightness of the weave (thread count), and the type of fabric finish. The permeability of the fabric, however, has little to do with the operation of the fabric under actual gas conditions.

Woven fabrics are available in several finishes. Cotton fabrics may be preshrunk to maintain dimensional stability (i.e., resistance to stretching or shrinking in any direction, which could adversely affect other fabric characteristics). Spun fiber fabrics may be napped on the surface that will receive the dust load. The napping process pulls fibers out of the yarn bundles to form a soft pile; this promotes the formation of a dust cake on the fabric surface that does not penetrate the interstices of the fabric. Synthetic fabrics may be heat-set to ensure dimensional stability and to provide a smooth surface with uniform permeability. Any fabric may be silicone-treated (also used in combination with graphite and Teflon) to improve abrasion resistance, to facilitate cake release, and to reduce moisture absorption. Fabric finish is extremely important for inside bag filtering, where nodules develop that restrict filtering (increase pressure drop) and interfere with cake release. The formation of nodules can be reduced by singeing the interior or exterior surface to remove fibers not tightly bound in the weave.

Fabric selection is usually based on the prior experience in similar applications. The following factors are important:

Dust penetration
Continuous and maximum operating temperatures
Chemical degradation
Abrasion resistance
Cake release
Pressure drop
Cost
Cleaning method
Fabric construction
Bag life desired

The choice of fabric ultimately affects pressure drop, selection of cleaning method, outlet concentration, and the life of the fabric under operating conditions.

Filter fabrics can further be broken down into the following three classifications: natural, synthetic, and mineral. The fibers included in each are as follows:

- Natural
  - Cotton
  - Wool
- Synthetic
  - Polypropylene
  - Nylon
  - Polyester (Dacron)
  - Nylon aramide (Nomex)
  - Acrylic (Dralon T)
  - Fluorocarbon (Teflon)
  - Polyphenylene sulfide (Ryton)
- Mineral
  - Glass
  - Ceramic
  - Stainless steel (or other exotic alloys such as Hastelloy and Chromalloy, depending upon the application)

Other substances can be used as coatings on these fabrics to improve their operating characteristics in specific environments. The most common coatings are Teflon and silicone/graphite.

The properties of commonly used fabrics and fabric coatings are discussed in conjunction with the gas stream properties that limit which fabric can be used in various applications. These properties are temperature, the chemical composition of the gas, and the abrasive nature of the particulate.

2.3.1.1 Gas Stream Properties Affecting Fabric Life--

Temperature--High temperatures accelerate the degradation of the polymer in synthetic and natural fabrics. Table 2-1 lists the continuous temperatures at which reasonable performance of the various fabrics can be expected

TABLE 2-1. RECOMMENDED TEMPERATURE LIMITS FOR VARIOUS FABRICS[1,2]

Fiber	Generic name	Maximum gas temperature, °F		Melting temperature, °F
		Continuous	Short-term	
Cotton	Natural fiber cellulose	180	225	420 decomposes
Wool	Natural fiber protein	200	250	575 chars
Nylon	Nylon polyamide	200	250	520
Dynel	Modacrylic	160	200	440 softens
Polypropylene	Polyolefin	200	250	440
Orlon	Acrylic	275	320	520 softens
Dacron	Polyester	275	325	440
Nomex	Nylon aromatic	400	425	640 decomposes
Teflon	Fluorocarbon	500	530	670 decomposes
Fiberglass	Glass	500	550	1070
Stainless		1000	No data	1700

(Adapted from Perkins, H.C. In: Air Pollution, A. Stern (ed.), McGraw Hill, New York, 1974).

under normal conditions, according to fabric manufacturers.[1] The maximum short-term temperature represents the temperature at which rapid deterioration will occur and result in immediate failure. For synthetics, this is the temperature at which polymer softening/polymer chain breakage occurs and causes permanent elongation.

Polymer finishes, such as Teflon, can also degrade at high temperatures. A few minutes of exposure to temperatures above the recommended continuous operating temperatures may not result in immediate failure, but will reduce the overall life of the fabric. The effects of repeated temperature excursions on tensile strength are cumulative.

Chemical composition--Chemical degradation of the fabric is caused by the breaking of polymer chains within the fiber structure. This can be caused by acid hydrolysis or alkali attack.

As the chain length of a polymer is reduced by chemical attack, it loses strength. The chemical attack may be accelerated by moisture or metal catalysts in the dust impregnated in the fibers. The rate of attack increases with temperature.

Chemical composition of the gas stream (along with its moisture content and temperature) must be considered in selection of the fabric. Table 2-2 presents the ratings of commercial fabrics with respect to chemical resistance. "Resistance" is a relative term; it does not imply total resistance to a specific chemical. Also, resistance may be greatly reduced by cyclic operation under different conditions and concentrations. Tables such as this must be used with caution. Polyester is generally rated as resistant to alkali attack, but at temperatures above 93°C (200°F) and in the presence of moisture, the polymer degrades rapidly. Cotton and Nomex are particularly susceptible to sulfuric acid attack below the acid dew point. The tensile strength of the fiber is reduced as the polymer chains are broken.

In general, the life of the fiber depends on proper fiber choice for application to acid gases such as SO_2, hydrogen chloride (HCl), and hydrogen fluoride (HF).

Abrasive dust--How well a fabric resists abrasion depends on fabric construction, fabric finish, and shapes of the particles collected. General

TABLE 2-2. CHEMICAL RESISTANCE OF COMMON COMMERCIAL FABRICS[1,2,15]

Fiber	Generic name	Acid resistance	Fluoride resistance	Alkali resistance	Flex and abrasion resistance
Cotton	Natural fiber cellulose	Poor	Poor	Fair to good	Fair to good
Wool	Natural fiber protein	Very good	Poor to fair	Poor to fair	Fair
Nylon	Nylon polyamide	Fair	Poor	Very good to excellent	Very good to excellent
Dynel	Modacrylic	Good to very good	Poor	Good to very good	Fair to good
Polypropylene	Polyolefin	Excellent	Poor	Excellent	Very good to excellent
Orlon	Acrylic	Good to excellent	Poor to fair	Fair	Fair
Dacron	Polyester		Poor to fair	Fair to good	Very good
Nomex	Nylon aromatic	Fair	Good	Excellent	Very good to excellent
Teflon	Fluorocarbon	Excellent	Fair to good	Excellent	Fair
Fiberglass	Glass	Fair to good	Poor	Fair	Poor
Polyethylene	Polyolefin	Very good to excellent	Poor to fair	Very good to excellent	Good
Stainless steel (type 304)		Excellent		Excellent	

abrasion of the fabric is accepted as a normal contributor to the failure of a bag over its life. Failure due to abrasion cannot be prevented, but the rate of abrasion can be reduced by properly installing the bags to avoid bag-to-bag contact, by maintaining proper tension, and by reducing the amount of dust being handled. In some applications, a cyclone may be installed as a precleaner to remove larger particles and reduce inlet loading. In other applications, however, the removal of larger particles may not be desirable because of dust cake considerations.

2.3.1.2 Other Factors Affecting Bag Life--

Local intensive abrasion--Local intensive abrasion, which can cause premature bag failure, can be prevented. High abrasion rates are commonly associated with improper bag installation or design flaws in the collector. Higher A/C ratios will also increase abrasion. Each case of abrasion failure must be addressed separately to determine if corrective action may be taken to reduce failure frequency.

Cleaning method--The method of removing the dust cake is closely related to fabric construction and fiber type. With woven fabrics that are subject to abrasion or flex damage, gentle cleaning methods such as low-frequency shaking or reverse air can be used. Felted fabrics require a more intense cleaning method, such as high-pressure reverse-air or pulse-jet cleaning. Use of an improper cleaning method with a fabric (e.g., intense shaking of glass bags) can cause premature fabric failure, incomplete cleaning, or blinding of the fabric (complete plugging of pores).

Pressure drop across filter--Greater stress on the fabric at higher pressure drops can decrease bag life.

2.3.2 Instrumentation

The following instrumentation contributes to the reliable operation of a fabric filter.

1. Thermocouples or other temperature-measuring instruments at the device inlet.

2. Inlet/outlet differential static pressure gages.

3. A double-pass transmissometer (opacity meter).
4. Compressed-air pressure gage.
5. Fan motor ammeter.

Recording temperature meters are especially useful in identifying high- or low-temperature excursions, which rapidly destroy fabrics. High-temperature indicators composed of colored fiber or temperature-sensitive plugs may be used as a less expensive alternative.

In lieu of differential pressure gages, it is sometimes simpler to install static pressure taps, where appropriate, and to use a portable meter to obtain readings. This approach reduces problems of meter moisture damage, meter corrosion, and plugging of lines. If permanent differential static pressure gages are used, the static pressure lines should be as short as possible and free of 90-degree elbows to minimize plugging. Copper tubing in a noncorrosive environment has been found to be less susceptible to deterioration than the polypropylene lines commonly used. However, PVC is even better because of its resistance to corrosive conditions.

The double-pass transmissometer may not provide an accurate measurement of effluent opacity; however, it is useful in identifying problems. A significant leak is detected in a specific compartment by a drop in the opacity when that compartment is off-line for maintenance in shaker and reverse-air fabric filters.[21] A pinhole leak can be identified in pulse-jet filters by an increase in opacity a few seconds after the row of bags that contains the pinhole leak is cleaned.

The instrument readouts should be mounted on a master control panel as close as possible to other process monitoring displays. The readings of thermocouples, pressure differential gages, and transmissometers can all be electronically recorded for permanent records.

2.3.3 Gas inlet equipment

If an adequately designed baffle plate is not used to remove large, abrasive particles, abrasion can occur, particularly on the surface of the bag near the cuff. More abrasion problems occur near the bottom of the bags, directly above the thimbles. The installation of thimble extensions, a blast plate, or a precleaner can reduce the abrasive damage and extend bag life.

Baffle plates or diffusers are used to cause large particles to deposit in the hopper before they contact the bags. The orientation of the plates is critical, however, because deflection of incoming gas into the hopper can resuspend collected dust and increase dust loading through the tube sheet. Less resuspension will occur if the hoppers are operated with continuous dust removal and the dust remains below the gas inlet. Screw conveyor discharge also should be on the opposite side from the gas inlet to minimize reentrainment. Because baffle plates suffer continuous erosion, they must be replaced periodically. An increase in bag ruptures near the cuff area may indicate the need to replace a baffle plate or to correct other problems with the tube sheet thimble.

A good thimble arrangement will also reduce abrasion at the bottom of bags in reverse-air and shaker-type collectors. The thimbles should be at least one bag diameter long to prevent abrasion caused by particulate "turning the corner" at the cell plate and being thrown to the outside by inertial force.[22] The thimbles act as flow straighteners and protect the bottom of the bag from excessive abrasion. A properly designed unit is shown in Figure 2-8. The rounded edge on the top of the thimble reduces cutting of the fabric even if tension is not optimum. For units in which the base snaps into the tube sheet, a thimble can be added that extends downward to provide the same type of abrasion protection as that shown in the illustration.

A bypass may be advisable, especially when process startup or upset conditions could generate sticky particulate or result in gas temperatures below the acid vapor or water dew points. These could also be used in conjunction with a spark sensor to reduce risk of fire.

Inlet and outlet dampers should be provided in compartmented systems to allow on-line maintenance. The dampers must be designed to provide positive sealing so as to protect maintenance personnel from toxic gases.

2.3.4 Hoppers and Dust Handling System

As solids are cleaned from the filtering fabric, they fall into a collection hopper for ultimate removal. The "fluid" properties of the collected solids are important to the design and operation of these systems, and they may be markedly different from the properties of the material from which they originated. Fine dusts, for example, tend to pack more readily

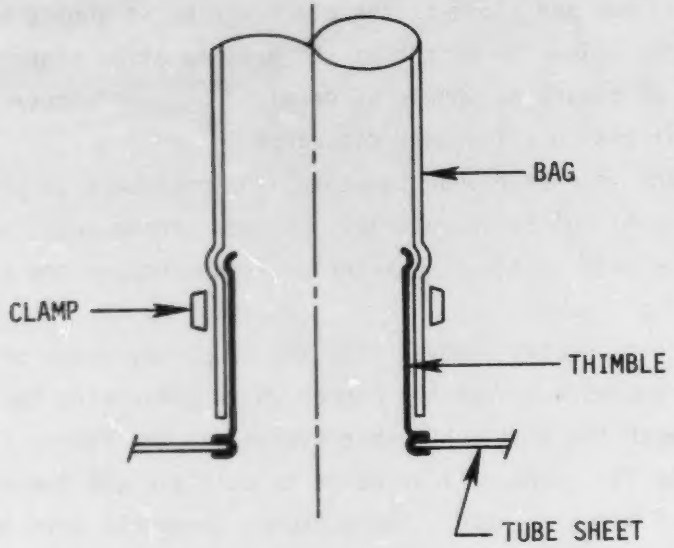


Figure 2-8. Cross section of a thimble protecting bottom of bag (Courtesy of Mr. E. W. Stanly).

than coarser materials; moreover, condensation formed in the filter device may cause solid material to agglomerate. Both of these factors can make solids disposal difficult.

Various design features can help to prevent the clogging of solid collection hoppers. The hopper should be designed with a steep valley angle; angles of 55 to 70 degrees are recommended. Hoppers should also include large discharge openings, well finished (smooth) surfaces, and minimal ledges or other obstructions on sidewalls. The top of the hopper sidewall should drop vertically and the slope to the discharge point should begin at least one bag diameter below the bottom of the bags to allow proper dust discharge. At least 1 ft of clearance should be provided between hopper walls and any internal partitions to allow easy discharge.

Heaters and insulation can be installed in hoppers to prevent condensation and caking of collected material. Hopper stones supplied with hot dry air can also be used to fluidize material in the hopper and keep it free-flowing.

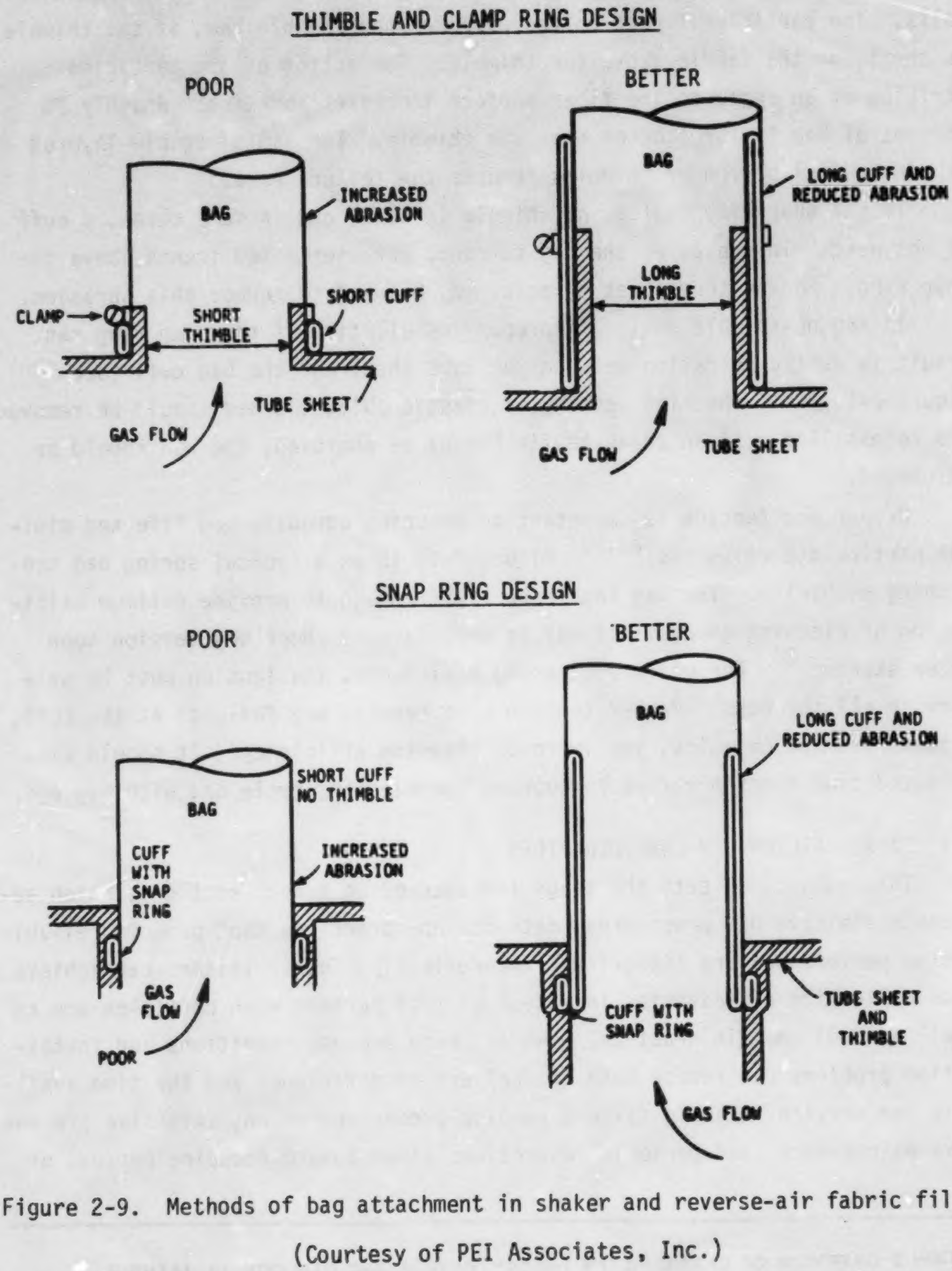
Solids are generally removed from the hopper by means of a discharge valve, which removes ash from the hopper while preserving the pressure differential between the dust conveyance system and the fabric filter system.

Insulating the fabric filter helps to maintain the temperature of the gas while it is being cleaned. Temperatures above the acid dew point minimize corrosion of hanger components, doors, and walls. Internal shell components can also be lined with appropriate corrosion-resistant materials if necessary. Insulation should be applied to the baghouse shell, hoppers, and doors. Structural steel may be placed on the internal portion of the shell. The insulation may then be applied evenly across the shell to reduce "cold spots," which promote corrosion of the shell.

2.3.5 Bag Support System

The bags and the associated fabric filter components (such as the tube sheet, clamps, thimbles, and bag cages) must be compatible for optimum bag life and control efficiency.

In shaker and reverse-air fabric filters, the bag can be attached to the tube sheet by a thimble and clamp-ring design or by a snap-ring design. Figure 2-9 shows the two methods of attachment. Dust enters the fabric filter



THIMBLE AND CLAMP RING DESIGN

SNAP RING DESIGN

Figure 2-9. Methods of bag attachment in shaker and reverse-air fabric filters.

(Courtesy of PEI Associates, Inc.)

at the hopper in a horizontal direction and must make a vertical turn to enter the tube sheet thimbles. Because heavy particles with higher inertia do not follow the flow, they do not enter the opening parallel to the thimble walls. The particles impact on the walls of the thimble and, if the thimble is short, on the fabric above the thimble. The action of the particles striking at an angle to the fiber surface increases abrasion. Roughly 90 percent of bag failures occur near the thimble. The use of double-layered fabric (cuffs) or longer thimbles reduces the failure rate.

In the snap-ring system, no thimble is used, and in some cases, a cuff is not used. This exposes the bag to rapid abrasion a few inches above the snap ring. Add-on tube sheet thimbles may be used to reduce this abrasion.

In the no-thimble design, improper installation of the snap ring can result in dust penetration between the tube sheet and the bag cuff (see Figure 2-10). If the ring seating is questionable, the bag should be removed and reinstalled. If an adequate fit cannot be achieved, the bag should be discarded.

Proper bag tension is important to ensuring adequate bag life and minimum particulate emissions.[22,23] Figure 2-11 shows a typical spring bag tensioning mechanism. The bag should be tight enough to provide optimum utilization of cleaning energy. It may be necessary to check bag tension soon after startup.[23] For uniform cleaning efficiency, the tension must be uniform in all the bags. Proper tension also reduces bag failures at the cuff, lessens wear on thimbles, and improves cleaning efficiency. It should also be noted that tension varies throughout the cleaning cycle and with bag age.

2.4 FABRIC FILTER O&M CONSIDERATIONS

This subsection sets the stage for succeeding manual sections, which address definitive O&M procedures, methods, and practices that promote reliable system performance and integrity. Theoretically, fabric filters can achieve mass collection efficiencies in excess of 99.5 percent when particles are as small as 0.01 μm. In practice, however, many process conditions and installation problems can reduce both the collection efficiency and the time available for service. Fabric filters require proper operation, extensive preventive maintenance, and periodic inspections aimed toward reducing periods of

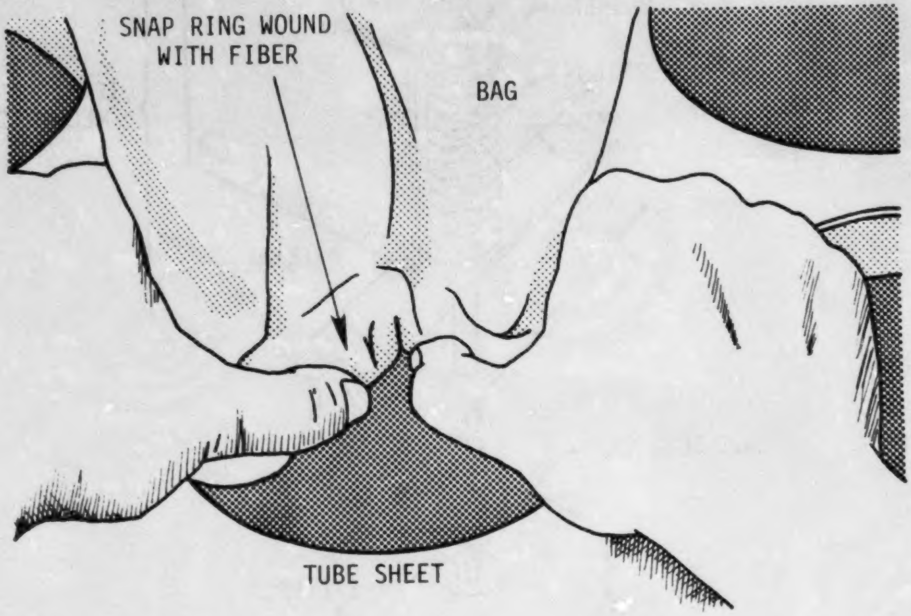

SNAP RING WOUND WITH FIBER
BAG
TUBE SHEET

Figure 2-10. Proper method of installing bag in tube sheet with snap rings. (Courtesy of PEI Associates, Inc.)

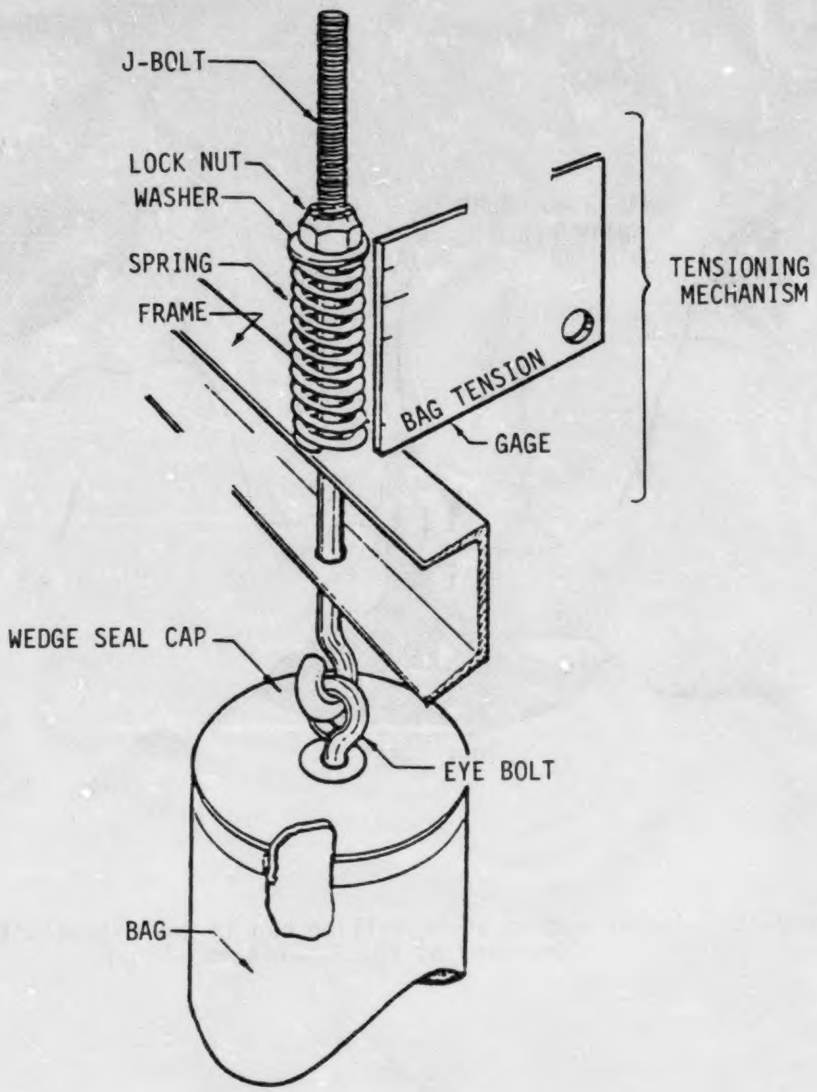


Figure 2-11. Typical spring bag tensioning arrangement.
(Courtesy of Industrial Clean Air)

excess emissions. Each of these is discussed in detail in the remaining sections of this manual, but they are touched on briefly here.

2.4.1 Causes of Poor Performance

Giving proper attention to the design, construction, and installation of the fabric filter system will enhance an O&M program. The design and configuration should allow accessibility to all operating components and the interior of the fabric filter for performance monitoring (Section 3), for troubleshooting (Section 4), for performing preventive maintenance (Section 5), and for making detailed inspections (Section 6). On larger conpartmented fabric filter systems, each compartment should be dampered (both automatically and manually) for isolation so that the entire fabric filter does not have to be off-line to perform needed maintenance. The installation of a fabric filter should be closely monitored by in-house environmental personnel for quality assurance during construction.

Of particular importance are welding of the tube sheet and housing, insulation work, and bag installation. Improper insulation, for example, can lead to condensation inside the fabric filter, and deterioration of the bags can result from chemical attack or bag blinding. Such deterioration will lead to premature bag failures, greater emissions, and increased maintenance costs for bag replacement. Leaks due to tube sheets not being completely welded to the filter housing and bags not being properly installed allow unfiltered exhaust gases to bypass the filter material (see Figures 2-12 and 2-13). Inferior workmanship and materials may lower the capital costs, but efficiency of the unit will suffer.

Troubleshooting is an important part of operation and maintenance. All potential causes of a problem should be investigated, not just the most obvious. Fabric failure, for example, is an obvious cause for a loss in particulate removal efficiency. Merely replacing the bag, however, may only temporarily solve the problem. Problems with the cleaning system, solids removal system, or other factors may have contributed to bag deterioration. In other words, just treating the symptoms does not always effect a cure. Section 4 details the techniques for effective performance evaluation, problem diagnosis, and correction.

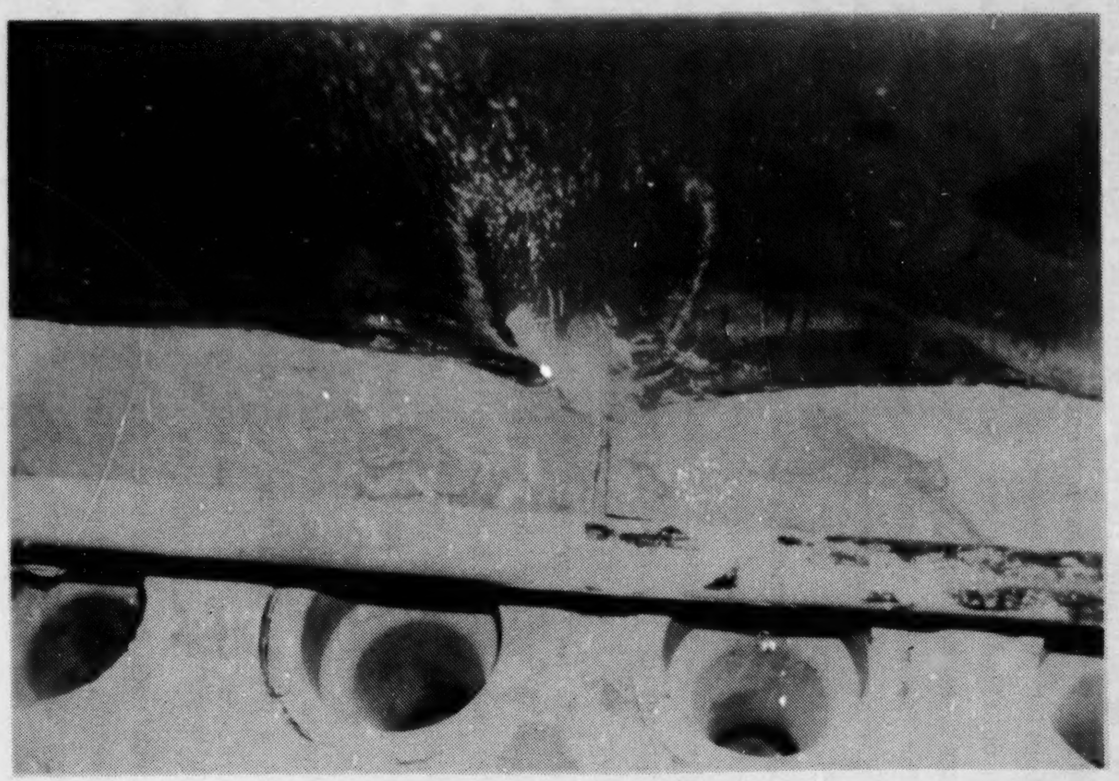


Figure 2-12. Tubesheet leak due to poor welding at wall of pulse-jet fabric filter. This results in a normal pressure drop but high continuous opacity. (Courtesy of PEI Associates, Inc.)

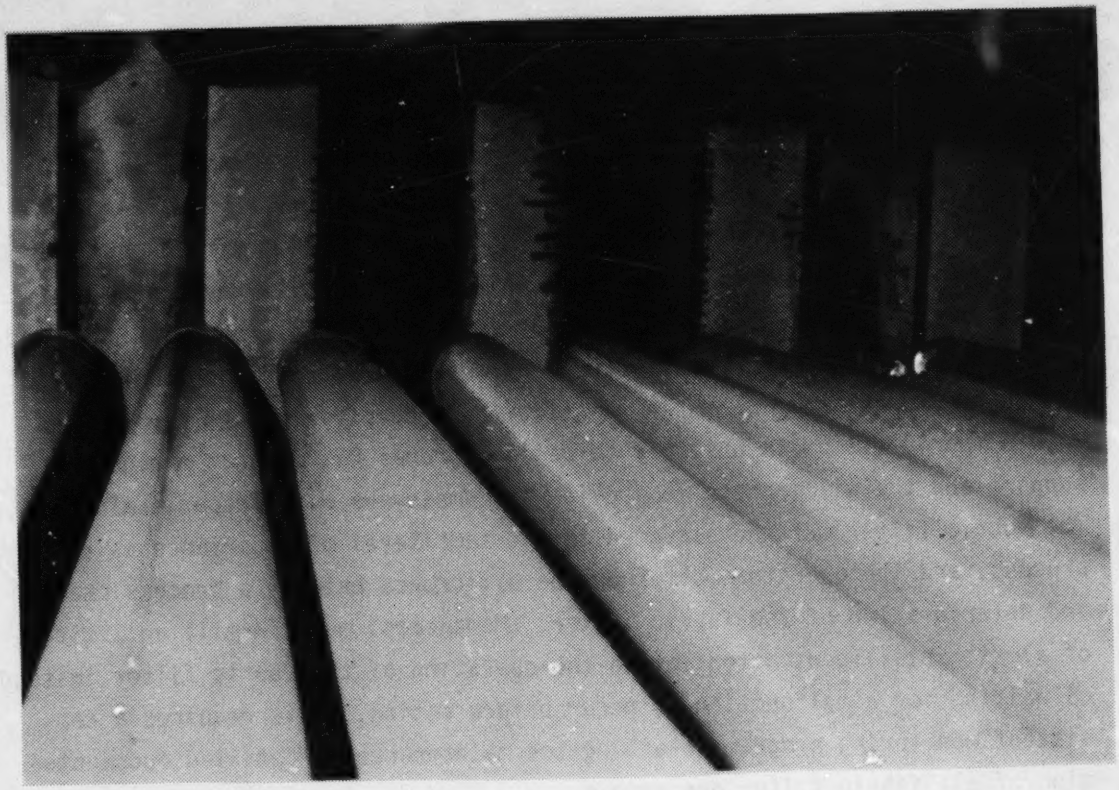


Figure 2-13. Broken weld on roof of fabric filter. This allows significant quantities of water to enter, and the water-sprayed bags can become blinded.
(Courtesy of PEI Associates, Inc.)

A good routine preventive maintenance program (Section 5) can minimize typical performance problems such as bag blinding, cleaning mechanism failure, and pinhole leaks (Section 3). Many of these problems, for example, can be minimized by routine maintenance of insulation, motors associated with the cleaning mechanisms and dust removal system, and temperature control instruments.

2.4.2 Establishing an Adequate Operation and Maintenance Program

Why should a plant make a concerted effort to maintain its fabric filter properly? The most convincing reason, outside of the necessity to meet applicable particulate emission regulations, is one of economics. A fabric filter is an expensive piece of equipment, and even well-designed equipment will deteriorate rapidly if improperly maintained and will have to be replaced long before it should be necessary. Not only can proper O&M save the plant money, it can also contribute to good relations with the local control agency by showing good faith in its efforts to comply with air regulations.

A fabric filter is unlikely to receive proper O&M without management support and the willingness to provide its employees with proper training. The fabric filter must be elevated to the same level of importance as the process, and the operator must know the difference between a process change and deterioration of the fabric filter. Management must instill an attitude of alert, intelligent attention to the operation of the fabric filter instead of waiting for a malfunction to occur before acting. This requires a consistent monitoring program entailing the maintenance of detailed documentation of all fabric filter operations.

Although each plant has its own method of conducting an O&M program, past experience has shown that plants that assign one individual the responsibility of tying all the pieces of the program together operate better than those where different departments look after only a certain portion of the program and have little knowledge of how that portion impacts the overall program. In other words, a plant needs to coordinate the operation, maintenance, and troubleshooting components of its program if it expects to be on top of the situation.

Some companies that have several plants have found it to be advantageous to set up a central coordinating office to monitor the O&M status at each plant. The resulting improved communications can provide an opportunity to develop standardized reporting forms, assistance in personnel training, interpretation of operating data, and routine inspections. With knowledgeable people in the central coordinating office, the plants have somewhere to go for assistance in solving problems for their specific kind of fabric filter.

Another resource that plants can draw upon is the manufacturer's field service engineer. This person is involved in pre-operational inspections to ensure proper assembly of fabric filter components; to set up the various controls within prescribed limits; to check for proper operation of the dust discharging system; to solve any existing problems after initial startup; and finally, to instruct plant personnel on how to perform these functions.

Experienced field service engineers can be very helpful as a resource for assistance in troubleshooting; however, because manufacturers are generally plagued with a high turnover rate, the plant should be wary of inexperienced people who may incorrectly diagnose operating problems or be unaware of proper correction procedures. This only adds to the confusion by misleading O&M personnel.

The training and motivation of employees assigned to monitor and maintain the fabric filter are critical factors. These duties should not be assigned to inexperienced people who do not understand how the fabric filter works or the purpose behind their assigned tasks. The employee must know what management expects and should receive encouragement for a job well done.

Regular training courses should be held by in-house personnel or by the use of outside expertise so that operators and maintenance personnel are instructed on everything they need to know in regard to the fabric filter. This should include written instructions and "hands-on" sessions on safety, how to make inspections while the fabric filter is both in and out of service, how to take operating parameter readings, how to perform routine maintenance, and how to record and use data. Training provides the knowledge necessary for proper operation and maintenance of the fabric filter and makes the employees' job easier because they will understand why they are taking pressure and temperature readings or searching for pinhole leaks.

In summary, the three separate components of an adequate plan for long fabric filter life are operation, maintenance, and troubleshooting. Each plant should have its own O&M procedures manuals, blueprints, and a complete set of fabric filter specifications; an adequate supply and record of spare parts; written procedures for addressing malfunctions; and formalized audit procedures.

Records should be kept on fabric filter operating conditions (process logs, fuel records, gas temperature, pressure differentials, etc.), equipment conditions (internal inspections; daily inspections of cleaning mechanisms, hoppers, compressors, etc.), maintenance (work orders, current work in progress, deferred work), and troubleshooting/diagnostic analysis (component failure frequency and locations, impact of process changes on fabric filter performance, and other trend-related analyses). Each of these areas is discussed in detail in later sections of this manual.

REFERENCES

1. Theodore, L., and A. J. Buonicore. Industrial Air Pollution Control Equipment for Particulates. CRC Press, Cleveland. 1976.

2. Perkins, H. C. In: Air Pollution, A. Stern (ed.). McGraw-Hill, New York. 1974.

3. Paretsky, L. L., T. R. Pfeffer, and A. J. Squires. J. Air Pollution Control Association, 21:4, April 1971.

4. Anderson, D. M., and L. Silverman. Harvard Air Cleaning Laboratory. AEC Report No. NYO-4615, 1958.

5. Donavan, R. P., J. H. Turner, and J. H. Abbott. Passive Electrostatic Effects in Fabric Filtration. Second Symposium on the Transfer and Utilization of Particulate Control Technology. In: Vol. 1. Control of Emissions from Coal Fired Boilers. F. P. Venditti, J. A. Armstrong, and M. Durham (ed.). EPA-600/9-80-039a, September 1980. pp. 476-493.

6. Donavan, R. P., R. L. Ogan, and J. H. Turner. The Influence of Electrostatically Induced Cage Voltage Upon Bag Collection Efficiency During the Pulse-jet Fabric Filtration of Room Temperature Fly Ash. In: Proceedings of the Third Symposium on Fabric Filters for Particle Collection. EPA-600/7-78-087, June 1978.

7. Frederick, E. J. of the Air Pollution Control Association, 24:1164-1168, December 1974.

8. Frederick, E. Chemical Engineering, 68:107, June 1971.

9. Dennis, R., and N. F. Suprenant. Research on Fabric Filtration Technology. EPA-600/8-78-005d. 1978. p. 151.

10. Dennis, R., and N. F. Surprenant. Research of Fiber Filtration Technology. EPA-600/8-78-005d, 1978, p. 151.

11. Bergmann, L. New Fabrics and Their Potential Application. J. Air Pollution Control Association, 24:1187-92, December 1974.

12. Mappes, T. E., and R. D. Tems. An Investigation of Corrosion in Particulate Control Equipment. EPA-340/1-81-002, February 1981.

13. Prinz, R. T. Reducing Baghouse Maintenance by Design. Minerals Processing, 11:8-13, May 1970.

14. Dennis, R., and H. A. Klemm. Fabric Filter Model. GCA Corporation, Bedford, Massachusetts. EPA-600/7-79-043a through EPA-600/7-79-043c, February 1979.

15. Reigel, S. A. Fabric Filtration Systems Design, Operation, and Maintenance. From Plant Inspection Workshop - Techniques for Evaluating Performance of Air Pollution Control Equipment. Selected Papers on Operation and Maintenance of Fabric Filters. Compiled by PEDCo Environmental, Inc., Durham, N.C., under U.S. Environmental Protection Agency, Contract No. 68-02-3512. February 1981. pp. 35-73.

16. Wheelabrator-Frye, Inc. Clearing the Air With Custom-Designed Fabric Filter Systems. Pittsburgh. Sales Literature. APC-11 15-7-7. 24 pp.

17. Pruce, L. M. Interest in Baghouses on Upswing. Power, February 1980. p. 87.

18. Burnett, T. A., and K. D. Anderson. Technical Review of Dry FGD Systems and Economic Evaluation of Spray Dryer FGD Systems. EPA-600/7-81-014, February 1981.

19. Lucas, R. L., et al. The Staclean Diffuser Increases Capacity and Reduces Bag Wear in Pulse-Jet Baghouses. Presented by duPont de Nemours & Company at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec, June 22-27, 1980. 16 pp.

20. Carr, R. C. Summary of Second Conference on Fabric Filter Technology for Coal-Fired Power Plants. J. of the Air Pollution Control Association, 33(10)949-954, October 1983.

21. Perkins, R. P. The Case for Fabric Filters on Boilers. Presented at Semiannual Technical Conference on Air Pollution Equipment, Philadelphia, Pennsylvania, April 23, 1976.

22. Ladd, K. L., Jr., et al. Objectives and Status of Fabric Filter Performance Study. In: Second Symposium on the Transfer and Utilization of Particulate Control Technology. Vol. 1, Control of Emission from Coal-Fired Boilers. F. P. Venditti, F. A. Armstrong, and M. Durham (ed.). EPA-600/9- 0-039a, September 1980. pp. 317-341.

23. Perkins, R. P., and J. F. Imbalzano. Factors Affecting Bag Life Performance in Coal-Fired Boilers. In: Proceedings of The User and Fabric Filtration Equipment III. E. R. Fredrick (ed.). APCA Specialty Conference. 1978. pp. 120-144.

24. PEDCo Environmental, Inc. Inspection and Operating and Maintenance Guidelines for Secondary Lead Smelters. Prepared for U.S. Environmental Protection Agency, Cincinnati, Ohio. June 1983. p. 66.

SECTION 3

FABRIC FILTER PERFORMANCE MONITORING

Performance monitoring is a key factor in establishing good operation and maintenance procedures for a fabric filter. It includes measurement of key operating parameters by both continuous and intermittent methods, comparison of these parameters with baseline and/or design values, and the establishment of recordkeeping practices. These monitoring data are useful in performance evaluation and problem diagnosis. In this section, the key operating data and procedures used in performance monitoring are discussed. Interpretation of the data is covered in Section 4.

3.1 KEY OPERATING PARAMETERS AND THEIR MEASUREMENT

Several operating parameters are indicative of a likely change in performance. Some of these parameters are easily measured and monitored on a continuous basis, whereas others must be measured only periodically because of the expense and/or difficulty in measurement. Most of these parameters, however, directly affect fabric filter performance. The following typical parameters are discussed here: gas volume and gas velocity through the fabric filter; temperature, moisture, and chemical composition of the gas; particle size distribution and concentration; and pressure drop across the fabric filter. Many of these factors are interrelated and affect critical fabric filter performance factors such as air-to-cloth ratio, the required cleaning energy and its effectiveness, and bag tension.

3.1.1 Gas Volume and Velocity

A change in gas volume and velocity affects the air-to-cloth ratio, the required cleaning energy and its effectiveness, and bag life. The collection efficiency also varies with fabric filter designs, but such variations are generally not significant unless the flow is increased beyond the design limitations. Higher gas volumes lead to higher air-to-cloth ratios and velocities, which shorten bag life as a result of more frequent cleaning, higher particle velocity through the fabric (more abrasion), greater potential for blinding, and a higher pressure drop.

A pitot tube traverse is normally used to measure total gas volume, and the method is usually a combination of EPA Reference Methods 1 and 2. In this method, the duct on the cross section of the stack is divided into a number of equal areas, and each area is sampled to arrive at an average velocity through the duct. When the average velocity and the duct or stack cross-sectional area is known, the average gas volume can be determined. Because most facilities do not routinely measure gas volume, other indirect indicators may be used to estimate the volume. These include fan operating parameters, production rate, and a combination of other gas condition parameters.

3.1.2 Gas Temperature

Monitoring the temperature of the gas stream can provide information about the performance of a fabric filter and clues for diagnosing both fabric filter performance and process operating conditions. The major concern in temperature measurement is to avoid sampling at a stratified point where the measured temperature is not representative of the bulk gas flow. Thermocouples with digital, analog, or strip-chart display are typically used.

The effect of temperature is most important as an indicator of excessive inleakage into the gas stream. Even the best-constructed and best-insulated fabric filter will experience some temperature drop, which can be as low as 1° to 2°F on smaller fabric filters and up to 25°F on very large fabric filters. Of course, the expected temperature drop will vary, depending on the temperature of the gas stream relative to ambient temperatures. In fact, the temperature drop is normally higher on small collectors than on large ones because the ratio of the outside collector area to gas throughput is generally higher. In any case, some acceptable or maximum difference between inlet and outlet gas temperatures should be set, which when exceeded, would indicate improper operation or a maintenance problem that requires correction.

Temperature monitoring is also important for minimizing bag damage due to temperature exposure above the fabric's design limits. Even a temporary excursion above fabric temperature limits can weaken bags. An alarm tied to a regularly maintained thermocouple probe may prevent bag failure due to temperature excursion. This alarm can be used in conjunction with an automatic method of protection, such as dilution air or bypass. The effects of repeated temperature excursions are cumulative, and temperature charts can be used to determine the potential for short-term failure due to temperature excursions. It should be noted that the use of only one probe does not represent the temperature in each section of the fabric filter, but rather only the average.

Both maximum and minimum fabric filter operating temperatures must be considered. The exposure of the fabric to temperatures above the maximum exposure temperatures can cause immediate failure due to complete loss of strength and permanent elongation (melting). Minimum temperatures are related to the dewpoint temperature of the gas stream. Operation of the fabric filter below this temperature can cause moisture or acid condensation and result in bag blinding or chemical attack of the fabric. Fabric life under these conditions depends on the proper initial choice for application to acid gases such as SO_2, hydrogen chloride (HCl), and hydrogen fluoride (HF).

3.1.3 Chemical Composition

Important factors regarding the chemical composition of the gas stream include moisture content and acid dewpoint. Operating a fabric filter at close to the acid dewpoint presents a substantial risk of corrosion, especially in localized spots close to hatches, in dead air pockets, in hoppers, or in adjacent heat sinks (such as external supports). If the operating temperature drops below the water dewpoint, either during startup or under normal operation, blinding of the bags can occur. Trace components such as fluorine also can attack certain fabrics. For example, fiberglass bags exposed to 200 ppm of HF at 500°F may last 2 years, while 1200 ppm of HF at 500°F may result in a bag life of only 2 months.

From a practical standpoint, the chemical composition of the dust and gas stream is a dynamic quantity, and any monitoring scheme can only point out an optimum range and the variability. Monitoring the level of certain compounds may prove useful in some instances; for example, in the combustion of coal, sulfur content, combustibles content, and chemical composition of the ash may provide supporting evidence when problems occur. In many instances, however, chemical composition is either not monitored or it is monitored for other purposes.

3.1.4 Mass Loading and Size Distribution

Mass loading and size distribution must be considered during the design of a fabric filter and also during operation; however, within certain limitations (±10 to 20 percent of design values), changes in these parameters do not seriously affect fabric filter efficiency. Nevertheless, an increase in mass loading may require more frequent cleaning of the bags as a result of faster filter cake buildup. When bag failures occur due to the presence of large abrasive particles, the use of a precleaner or a gas distribution device (i.e., an inlet diffuser) at the fabric filter inlet may be required. For some sources, such as spreader stoker boilers, installation of a mechanical collector ahead of the fabric filter may be necessary to protect the bags from the large number of >10-micrometer particles and from glowing embers.

Mass loading at the inlet and outlet of the fabric filter is usually measured by standard EPA reference methods. The difference between the amount of material in the outlet gas stream and the inlet gas stream provides the basis for removal efficiency calculations. The use of the reference sampling methods, however, can be difficult on processes that generate very high mass loadings at the fabric filter inlet. When outlet mass loadings are very low, long sampling times may be required to collect enough material for accurate weighing. Also, simultaneous sampling of inlet loadings during the entire test period may not always be possible if the loadings are so high that the sampling train becomes overloaded. In some instances, a series of probes inserted for 1 to 15 minutes to take "grab" samples of the inlet concentration may be all that is technically feasible. Although this may not provide as accurate a value for inlet mass loading as would an "integrated" sample taken concurrently with the outlet emissions test, it will give a reasonable value to work with.

Particle size distribution is usually determined through the use of cascade impactors. Various types of cascade impactors are available with different particle cut sizes and for different mass loadings. A typical cascade impactor system is presented in Figure 3-1. The cascade impactor is

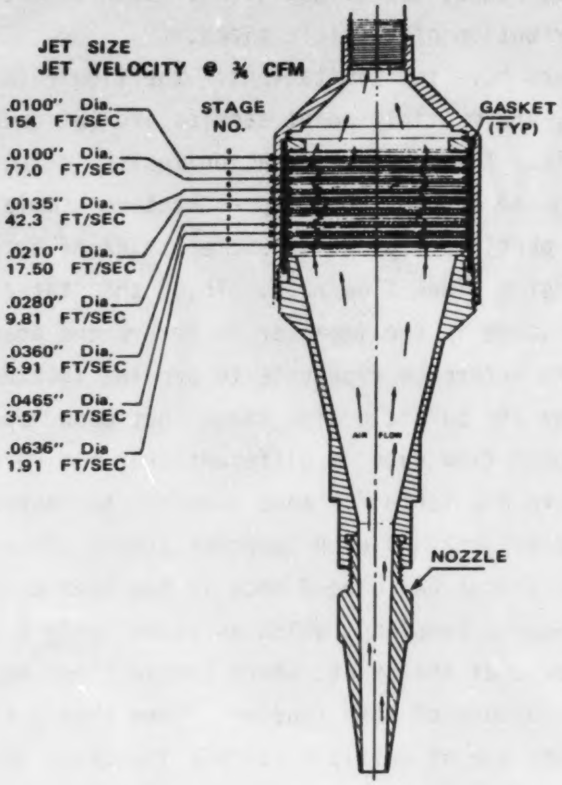


Figure 3-1. Typical cascade impactor system (courtesy of Andersen Samplers, Inc.).

usually placed on a standard sampling probe and inserted into the gas stream for isokinetic sampling of the particulate. A sampling train with a cascade impactor is illustrated in Figure 3-2. After sampling is completed, each stage of the impactor is weighed in the lab and compared against its initial weight to determine distribution. Because the impactor consists of several stages (usually five to nine) and each stage corresponds to a progressively smaller particle size range, the weight gain of each successive stage provides a weight distribution of particle sizes.

Cascade impactors have two limitations: the flow rate cannot be varied during the test run, and multiple-point samples are not usually possible with a single sample train. The sampling location must be selected carefully to avoid stratification and to provide a representative sample that will produce valid results. The particle capture characteristics of a cascade impactor are calibrated against a given flow rate. Thus, the stated particle size range for any given stage in the impactor is referenced against a fixed flow rate. Changes in the reference flow rate to provide isokinetic sampling in the stack will change the particle size range that each impactor stage will capture. If the chosen flow rate is different from the reference value, calibration curves are available for each impactor to correct for changes in the particle size sensitivity of each impactor stage. Thus, the flow rate through the impactor cannot be changed once it has been established. This necessitates single-point sampling, which is essentially a grab sample. The situation is even worse at the inlet, where sample times may be limited to only 1 to 2 minutes because of mass loading. More than a single-point sample may be obtained by the use of multiple cascade impactors to sample a number of different points. This is both equipment- and labor-intensive; however, it may provide an indication of the representative nature of a single-point sample.

3.1.5 Pressure Drop

Each fabric filter is designed to operate at a specific pressure drop or within a certain range. If the fabric filter is operating properly, the pressure drop should remain fairly steady during normal operation, with a gradual increase as the filter cake builds up on the bags and a steep decrease immediately after the bags are cleaned. Pressure measurements alone

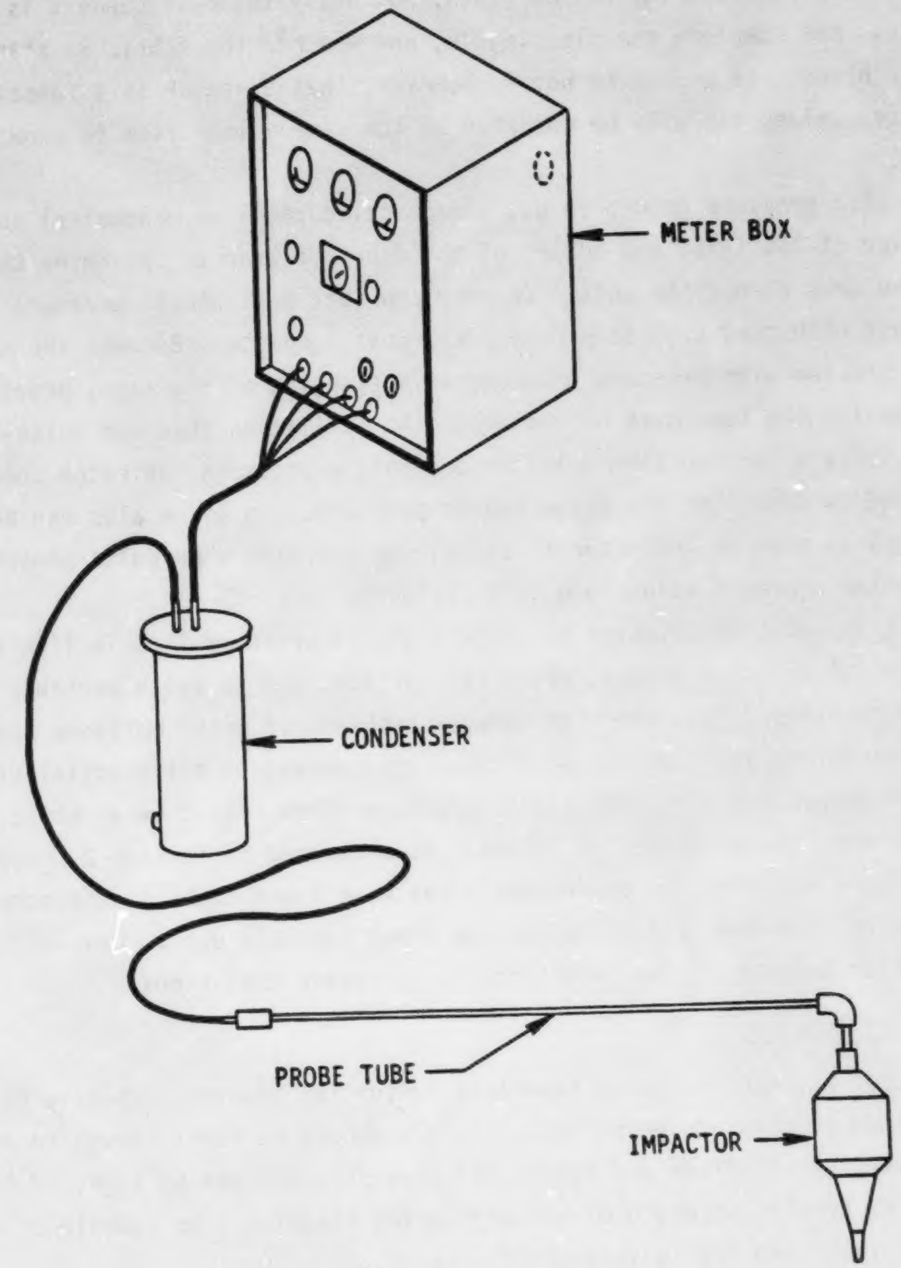


Figure 3-2. Sampling train with cascade impactor.
(Courtesy of PEI Associates, Inc.)

indicate the permeability of the cloth, how heavy the dust deposit is before cleaning, how complete the cleaning is, and whether the fabric is starting to plug or blind. It should be noted, however, that since ΔP is a function of velocity, values can only be compared at the same volume flow to show fabric change.

Static pressure gauges (e.g., a magnehelic gauge or manometer) should be installed at the inlet and outlet of the fabric filter to determine the pressure drop across the unit. In many applications, static pressure indicators must withstand high temperature and dust loadings. Because the most common problem with pressure indicators is plugging of the taps, provisions for cleaning the taps must be included. At facilities that use pulse-jet fabric filters for fugitive emission control, a pressure indicator should be installed to determine the pulse header pressure. An alarm also can be connected to such an indicator to signal the operator when pulse pressure drops below a preset value (e.g., 70 lb/in.^2).

It is sometimes simpler to install static pressure taps in lieu of differential pressure gauges, where appropriate, and to use a portable meter to take readings. This approach reduces problems of meter moisture damage, meter corrosion, and plugging of lines. When permanent differential static pressure gauges are used, the static pressure lines should be as short as possible and free of 90-degree elbows. As mentioned in Section 2, copper tubing (in a noncorrosive environment) has been found to be less susceptible to deterioration than the polypropylene lines commonly used. However, PVC is even better because of its resistance to corrosive conditions.

3.1.6 Bag Tension

Proper bag tension is an important factor for ensuring adequate bag life and minimum particulate emissions. The bag should be tight enough to avoid excessive fiber-to-fiber and bag-to-bag abrasion, but not so tight as to exceed the tensile strength of the bag during cleaning. An example of a properly tensioned bag is shown in Figure 3-3.

Upon installation, each bag must be checked for proper tension. The manufacturer's literature should be consulted to determine the correct tensioning method. The proper bag cleaning requires flexing of the surface to

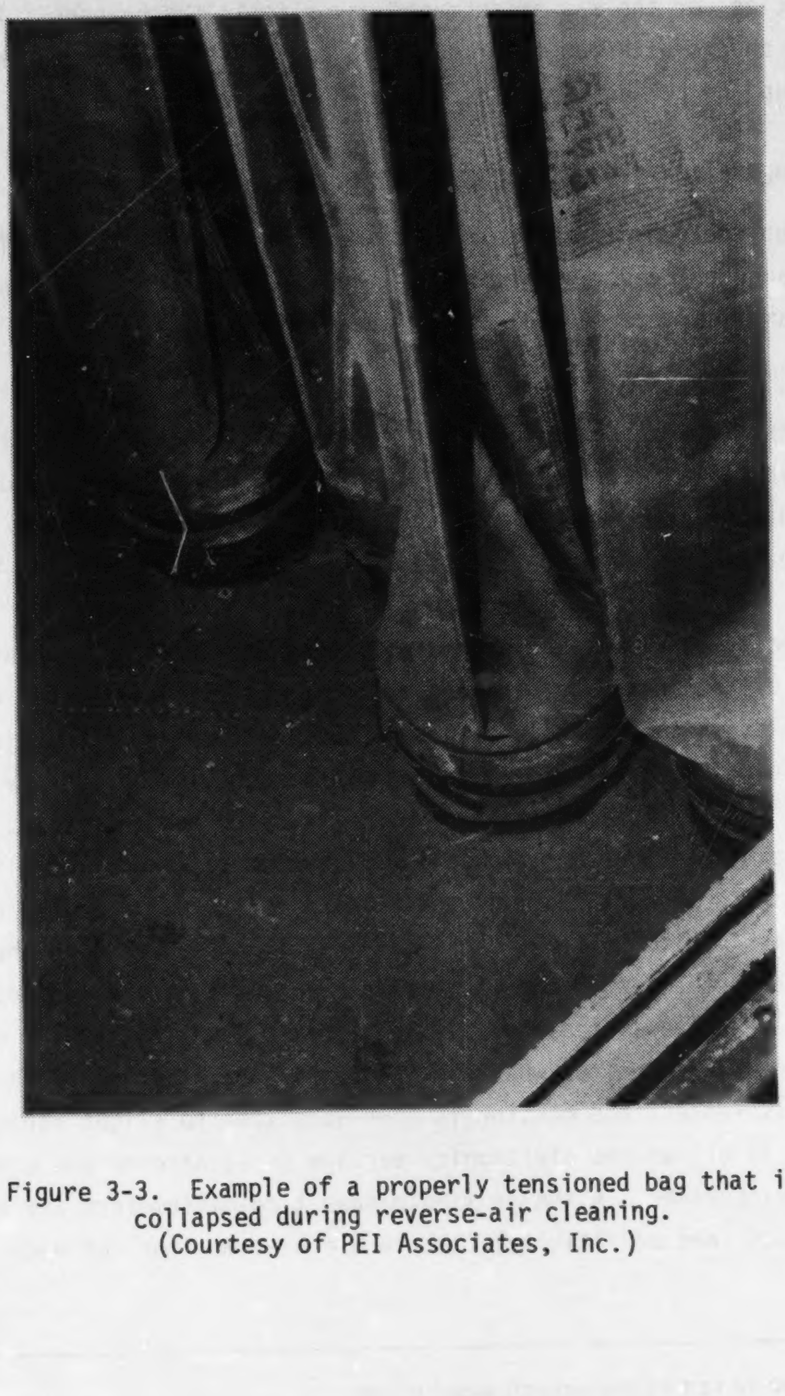


Figure 3-3. Example of a properly tensioned bag that is collapsed during reverse-air cleaning.
(Courtesy of PEI Associates, Inc.)

dislodge the cake, and if bag tension is low, the bag may be flexed adequately at the top, but the standing wave will dampen as it moves downward. Also, the fabric may elongate because of the weight of dust collected between cleaning cycles, or the bag attachments may slip in the hangers. Thus, tension may change with length of service, and it also should be checked soon after startup and periodically thereafter.

3.2 INSTRUMENTATION SYSTEMS AND COMPONENTS

Numerous instruments may be used to monitor fabric filter performance and performance changes. These include the usual pressure and temperature sensors, transmissometers, and hopper level indicators.

3.2.1 Transmissometers

Transmissometers can be useful for determination of fabric filter performance levels. A facility may have one or more monitors that indicate opacity from various fabric filter outlet ducts and from the stack itself. Opacity also may be measured on a real-time basis or over selected averaging periods.

The opacity monitor simply compares the amount of light generated and transmitted by the instrument against the quantity received by the receiver. The difference, which is caused by absorption, reflection, refraction, and light scattering by the particles in the gas stream, is the opacity of the gas stream. Opacity is a function of particle size, concentration, and path length. Opacity monitors are typically calibrated to display opacity at the stack outlet path length. Most of the opacity monitors now being installed are double-pass monitors; i.e., the light beam is passed through the gas stream and reflected back across to a transceiver. This arrangement is advantageous for several reasons: 1) it allows automatic checking of the zero and span of the monitor when the process is operational; 2) because the path length is longer, the monitor is more sensitive to slight variations in opacity; and 3) all of the electronics package is located on one side of the stack as a transceiver. Although single-pass transmissometers are available at a lower cost (and sensitivity), the double-pass monitor can meet the requirements for zero and span in Performance Specification 1, Appendix B, 40 CFR 60. Monitor siting requirements are also discussed in Performance Specification 1.

For many sources, mass-opacity correlations can be developed to provide a relative indication of fabric filter performance. Although site-specific, these correlations can provide plant and agency personnel with an indication of relative performance levels at a given opacity and deterioration in performance that requires attention by plant personnel.

When parallel fabric filters or chambers are used, an opacity monitor can be placed in each outlet duct, as well as on the stack, to measure the opacity of the combined emissions. Although the stack monitor is commonly used to indicate stack opacity (averaging opacities from different ducts can be difficult), the individual duct monitors can be used to determine bag integrity in each chamber and for troubleshooting. Although this option is often not required and it represents an additional expense, it can be very useful, particularly on relatively large fabric filters.

3.2.2 Hopper Level Indicators

Hopper level indicators could more accurately be called high hopper level alarms because they do not actually measure dust levels inside the hopper; instead, when the dust level becomes higher than the level detector, an alarm sounds to indicate that corrective action is necessary. The level detector should be placed high enough that "normal" dust levels will not continuously set off the alarm, but low enough to allow adequate response time to clear the hopper before the dust reaches the tube sheet and causes blocking of the inlet to the bags. Not all fabric filters use or need hopper level indicators.

Two types of level indicators are most commonly used (although others are available). The older of the two, a capacitance probe, is inserted into the hopper. As dust builds up around the probe, a change in the capacitance occurs and triggers an alarm. Although these systems are generally reliable, they can be subject to dust buildup and false alarms in some situations. The newer system, currently in vogue, is a nuclear or radioactive detector. These systems use a shielded Cesium radioisotope to generate a radioactive beam that is received by a detector on the opposite side of the hopper. Ash intercepting the beam decreases the detector signal and triggers a response.

This system has two advantages: 1) it does not include a probe that is subject to dust buildup, and 2) more than one hopper can be monitored by one radioactive source. Its major drawback is that plant personnel must deal with a low-level radioactive source, which means adequate safety precautions must be taken. These detectors are provided with safety interlocks to prevent exposure of plant personnel when maintenance is required.

Hopper level detectors normally should be placed between one-half and two-thirds of the way up the side of the hopper. As long as hoppers are not used for storage, this should provide an adequate safety margin. (It should be remembered that it takes much longer to fill the upper 2 feet of a pyramid hopper than the lower 2 feet.)

Other indirect methods are available for determining whether the hopper is emptying properly. On vacuum discharge/conveying systems, experienced operators can usually tell where the hopper is plugged or if a "rat-hole" is formed by checking the time and vacuum drawn on each hopper as dust is removed. On systems that use a screw conveying system, the current drawn by the conveyor motor can serve as an indicator of dust removal. Another simple method for determining hopper pluggage is through a thermometer located approximately two-thirds of the way up on the hopper. If dust covers the probe because of hopper buildup, the temperature will begin to drop, which signals the need for plant personnel to take corrective action.

3.3 PERFORMANCE TESTS AND PARAMETER MONITORING

The operating characteristics of a fabric filter are such that several concepts are useful in a performance evaluation. Among these are parameter monitoring and baseline assessments. These concepts form the basis for good recordkeeping and a preventive maintenance program aimed at achieving continuous compliance of the controlled source.

Regulatory compliance is determined by a performance test involving the use of a Reference Method, such as Method 5 or Method 17. In between these periodic performance tests during operations at maximum and normal operating conditions, compliance with visible emissions standards also may be determined by opacity observations performed in accordance with requirements of Reference Method 9. Because these emission tests represent only a small segment of time in the daily operation of the process and fabric filter, the performance during the emissions test may not be representative of characteristic daily operations. Nevertheless, these emissions tests do afford the opportunity to document process and fabric filter operating conditions that influence performance. By providing a known level of performance, these values serve as a benchmark or baseline condition for future comparisons with data collected during routine parameter monitoring and recordkeeping or as part of diagnostic troubleshooting. The establishment of these baseline conditions makes it possible for a number of parameters to be compared to determine their effect on performance. It is the magnitude of these changes that is important. In addition to the data obtained during emission testing, baseline conditions may include both pressure and temperature drop across fabric filter (average as well as before and after cleaning) and cleaning frequency.

Parameter monitoring, an extension of baselining the fabric filter and process equipment, forms the basis of diagnostic recordkeeping and preventive maintenance. Several key parameters are usually monitored to track fabric filter performance. Generally, parameter monitoring includes both process and fabric filter data because both are important to fabric filter performance. An analysis of these key parameters and a comparison with baseline values can define many performance problems, indicate the need for maintenance, and define operating trends within the fabric filter (see Section 4).

3.3.1 Performance Tests

The performance test often is the deciding factor for the acceptance of a new fabric filter, and many agencies require periodic testing (anywhere from quarterly to once every 3 to 5 years). The initial performance test certifies that the fabric filter is designed to be capable of meeting the specifications. These initial performance tests may also include tests with sections of the fabric filter out of service to meet special requirements of the permit, specifications, or regulatory requirements. The initial performance tests may also include inlet tests to establish grain loading, collection efficiency, and, in some cases, inlet particle size characteristics.

Testing requirements vary from site to site, and they should be established in a testing protocol; however, one of two test methods is generally specified for determining particulate emission rates. These are EPA Reference Methods 5 and 17 (40 CFR 60, Appendix). In both methods, a sample is removed isokinetically (i.e., the linear velocity of the gas entering the sampling nozzle is equal to that of the undisturbed gas stream at the sampling point) from various sample locations to prevent the sample results from being biased. The main difference between the two methods is the location of the filter in the sample train. The Method 5 sample train uses an external filter held in a temperature-control hot box. The sample passes through the heated sample probe and filter into the impinger train for removal of condensable materials (water, acid, and condensible organics). The particulate emission rate usually will be determined from the probe and filter catch alone (front-half catch); however, some regulatory limitations specify the use of both front- and back-half catches (which include the impinger catch minus water). In most cases, the specified temperature is 248° ± 25°F for the filter of a Method 5 sample train, but special conditions allow a temperature up to 320° ± 25°F.

Method 17, on the other hand, uses an in-stack filter to capture particulate. After the filter temperature has been allowed to equilibrate to stack conditions, the sample is drawn through the nozzle and into the filter. The sample is then passed through a set of impingers to remove condensibles from the gas stream.

The two methods often do not provide equivalent results, even when the flue gas temperature is the same as the hot box temperature. First, Method 5 defines particulate as the material that is captured on a filter at the hot box temperature (nominally 250°F), even though the temperature of the gas stream passing through the filter may be substantially different from the hot box temperature. This is important because many "particulates" are temperature-dependent, i.e., they exist below a certain temperature, but they may remain in a gaseous form above a given temperature. Theoretically, particulate matter is referenced to a particular temperature. Second, some losses are normally associated with recovering the particulate from the in-stack filter of the Method 17 sample train, and an average correction must be applied (e.g., 0.04 gr/scf for kraft recovery boilers). Lastly, because Method 17 is referenced to the stack temperature, the definition of what constitutes "particulate" may be different. Method 17 is usually reserved for particulates or processes that are not temperature-dependent. When this is the case, the results of both methods are usually in relatively close agreement.

There has been widespread discussion as to which method should be used when a choice is allowed. Each method can be manipulated to provide the most favorable emission rate. Method 17 may reflect more accurately the conditions the fabric filter may encounter; however, Method 5 attempts to standardize the operating temperature so that differences in temperature and temperature dependency are minimized.

In addition to overall particulate emission rates, some regulations limit the emission of fine particles. Such limits require particle size analysis, either by microscopic methods or by the use of cascade impactors. Cascade impactors are placed in the stack in a manner similar to the placement of an in-stack filter. An impactor consists of a series of perforated plates and target or impact stages on which an impact medium (e.g., grease) is used. As the gas and particulates pass through the impactor, they are accelerated to higher velocities. The particulate matter has difficulty staying with the flow streamlines, and its inertia carries it to impact the target stage. Each stage is sized to capture a predetermined particle size range at a given flow rate. Calibration curves and corrections to the particle size ranges are provided by the equipment manufacturers.

There are two problems related to the use of cascade impactors. First, the gas stream must be sampled isokinetically to avoid skewing of the particle size distribution. Under-isokinetic sampling (at a probe velocity less than that of the stack or duct) usually results in a distribution skewed toward large particles, whereas over-isokinetic sampling undersamples the large particles. Also, the particle size distribution may have little bearing on the Method 5 results because of the temperature-dependency of the particulate. Second, the isokinetic sampling requirement means that the sample must be drawn at a given flow rate and the flow rate cannot be varied to maintain calibration of the impactor. Varying the flow rate would vary the particle size distribution each stage would capture. This usually results in the use of single-point sampling or an "average" isokinetic rate for the test ports, with all the attendant limitations regarding sample representativeness. In some cases, multipoint sampling may be carried out, but careful planning and, for multiple impactors, good flow distribution are necessary.

Opacity is usually monitored during the performance test with an opacity monitor and/or by Method 9 observations. Several sources (most notably utilities) have done some work to establish mass/opacity correlations, which prompt the following general observations. First, mass/opacity correlations appear to depend on a number of industry- and site-specific factors, including size distribution, stack path length, and process-related factors. Second, over a period of time, consistent relationships have been found at a number of sources (regardless of process load), provided neither the process nor the fabric filter is experiencing severe malfunctions. The process operation seems to be the controlling factor in most cases. For example, much of the data for utility applications suggests that the mass/opacity relationship is relatively constant for a given source; however, when a condensible particulate is present, the mass/opacity correlation may not be reliable. Third, opacity monitor data tend to produce "tighter" or better correlations than Method 9 when 95 percent confidence intervals are calculated for the correlation. Observer biasing can result from changing background conditions or from "between-observer" differences; whereas a properly maintained monitor usually is not subject to biasing problems. Lastly, confidence intervals tend to become very large at the extreme ends of the curves when mass and/or opacity is either very low or high. At the low mass/opacity end of the curve, the relative errors, particularly in test methods, can become substantial. Although the mass loading is very high at the upper end, little change may occur in opacity. In the opacity ranges of interest to most agencies and sources, however, the confidence intervals can be quite tight. This opacity correlation, although not usually used for compliance determinations, can be useful in evaluating operation and maintenance, which was the original intent behind the requirement for continuous emission monitors.

3.3.2 Baseline Assessment

The establishment of baseline conditions for a fabric filter during a performance test provides a basis for comparison in future evaluations of the fabric filter. The baseline serves as a reference point, and the types and magnitude of shifts from baseline conditions are important in evaluating fabric filter performance.

Fabric filter baseline conditions generally can be established during the unit's initial performance test. The following key parameters should be examined during subsequent performance tests and compared against the baseline values:

1. Gas volume. If too high, it can blind the bags; if too low, it can cause dust dropout in the ducts.
2. Temperature. If too high, it can destroy the bags and/or gasketing; if too low, it might cause excursions below the dewpoint.
3. Pressure drop. A pressure drop that is too high indicates potential bag blinding or high gas flow; one that is too low indicates bag failure.
4. Dust load. If too high, it may exceed the unit's capacity to convey the dust from the baghouse; if too low, it may cause excessive emissions after each cleaning cycle.
5. Particle size. Particles that are too fine can cause blinding of the bags or excessive emissions.

Baseline conditions should also be established for the process that the fabric filter controls. Process data may include production weight, raw material and product feed characteristics, operating temperatures and pressures, combustion air settings, and cycle times (for cyclic processes).

Although the exact effect a change in most of these parameters will have on performance cannot be predicted, a qualitative evaluation can often be made when values deviate from baseline conditions, and these deviation values are useful in parameter monitoring.

3.3.3 Parameter Monitoring

Parameter monitoring usually plays a key role in an overall operation and maintenance plan, particularly one that stresses preventive maintenance. Such monitoring also forms the basis for a recordkeeping program that places emphasis on diagnostics. Typically, daily operating data are reduced to include only the data on a few key parameters that are monitored. Acceptable ranges may be established for various parameters (by use of baseline test data) that require further data analysis, or perhaps some other action if the values fall outside a given range. Care must be taken not to rely on just one parameter or indicator; other factors, both design- and operation-related, usually must be considered. Typical parameters that can be monitored include opacity and pressure drop during cake buildup, and gas temperature.

Many sources use opacity levels as the first indicator of performance changes. In general, opacity is a good indicator and tool for this purpose. It is not wise to rely on opacity data alone, however, as such reliance can cause one to overlook problems that can affect long-term performance (e.g., hopper pluggage or bridging within bags may not significantly increase opacity, but may eventually decrease the net cloth area and increase pressure drop).

Another useful parameter is the pressure differential across the fabric filter. Static pressure drop should be measured periodically to determine relative changes in dust cake resistance. When reviewing the operating logs, the operator should look for any increase above the previous operating levels in the lower (after the cleaning cycle) and upper (before the next cycle begins) pressure drops across the bags. A gradual increase in resistance can indicate oil deposits, fine particulate blinding of fabric, or moisture inleakage. An increase may be tolerated if it is not severe or if a decreased ventilation performance does not result from the decreased volume of gas exhausted. Temperature charts must be monitored to determine the potential for short-term failure caused by temperature excursions and to detect inleakage to the fabric filter housing. It is an unfortunate misconception that short temperature excursions do not cause permanent damage, as the effects of repeated temperature excursions on tensile strength are cumulative. A significant decrease in temperature across the fabric filter may indicate inleakage of outside air, either because of failure of gaskets around openings or the loss of the integrity of the housing.

3.4 RECORDKEEPING PRACTICES AND PROCEDURES

Recordkeeping practices for fabric filters range from none to maintaining extensive logs of operating data and maintenance activities and storing them on computer disks. The data obtained by parameter monitoring form a basis for recordkeeping, as this type of data usually indicates fabric filter performance. Recordkeeping allows plant personnel to track fabric filter performance, evaluate trends, identify potential problem areas, and arrive at appropriate solutions. The magnitude of the recordkeeping activity will depend on a combination of factors, such as personnel availability, size of the fabric filter, and the level of maintenance required. For moderately sized, well-designed, and well-operated fabric filters, maintaining both daily operating records and maintenance records should not be too cumbersome; however, records should be limited to key operating parameters only to avoid accumulating a mountain of unnecessary information.

When setting up a recordkeeping program, one should give attention to both operating and maintenance records because they are required to provide a complete operating history of the fabric filter. This operating history is useful in an evaluation of future performance, maintenance trends, and operating characteristics that may increase the life of the unit and minimize emissions. Even though recordkeeping programs are site-specific, they should be set up to provide diagnostic and troubleshooting information, rather than merely for the sake of recordkeeping. This approach makes the effort both worthwhile and cost-effective.

Other supplementary records that should be maintained as part of the permanent file for operation and maintenance include all baseline assessments that include both process and fabric filter operating data and data from emission tests. A spare parts inventory listing also should be maintained, with periodic updates so that parts may be obtained and installed in a timely manner.

3.4.1 Operating Records

As mentioned previously, the specifics on what parameters will be monitored and recorded and at what frequency will be largely site-specific. Nonetheless, the factors that are generally important in parameter monitoring will also be the ones recorded as part of a recordkeeping program. Such data would typically include the process operating rate, differential pressures, temperatures, and opacity monitor readings. These data probably should be gathered at least once per shift. The greater the frequency of data gathering, the more sensitive the operators will be to process or fabric filter operational problems, but the amount of data to manipulate also increases. The optimal frequency may be every 4 hours (twice per shift). In the event of sudden and dramatic changes in performance, this allows relatively little time to evaluate the data to determine the cause of the change. Shorter intervals might be required on highly variable sources.

In addition to the numerical values of the operating parameters, a check list should be included to confirm operation of the cleaning system, hopper systems (or other dust-removal systems), the absence of audible inleakage, and the other general physical considerations that can adversely influence fabric filter performance.

3.4.2 Maintenance Records

Maintenance records provide an operating history of a fabric filter. They can indicate what has failed, where, and how often; what kind of problems are typical; and what has been done about them. These records can be used in conjunction with a spare parts inventory to maintain and update a current list of available parts and the costs of these parts.

The work order system provides one of the better ways to keep maintenance records. When properly designed and used, this system can provide information on the suspected problem, the problem actually found, the corrective action taken, time and parts required, and any additional pertinent information. The system may involve the use of triplicate carbon forms or it may be computerized. As long as a centralized system is provided for each maintenance activity, the work order approach usually works well.

Another approach is to use a log book in which a summary of maintenance activities is recorded. Although not as flexible as a work order system (e.g., copies of individual work orders can be sent to various appropriate departments), it does provide a centralized record. This type of maintenance record is probably better suited for the facility that uses smaller fabric filters.

In addition to these centralized records, a record should be maintained of all periodic checks or inspections. These should include the weekly, monthly, semiannual, and annual checks of the fabric filters that make up part of a preventive maintenance program. Specific maintenance items identified by these periodic inspections should be included in the recordkeeping process. The items to be checked are discussed in more detail in Sections 4, 5, and 6.

3.4.3 Retrieval of Records

A computerized storage and retrieval system is ideal for recordkeeping. A computer can manipulate and retrieve data in a variety of forms (depending upon the software) and also may be useful in identifying trends. A computerized system is not for everyone, however. The larger the data set to be handled, the more likely it is that a computer can help to analyze and sort data. For a small source with a fabric filter that presents few problems and that has a very manageable set of operating parameters to be monitored, a computer system could be very wasteful (unless computing capability is already available). Also, it is sometimes easier to pull the pages from a file manually, do a little arithmetic, and come up with the answer than to find the appropriate disks and files, load the software, and execute the program to display "the answer."

Retention time is also a site-specific variable. If records are maintained only to meet a regulatory requirement and are not used or evaluated, they can probably be disposed of at the end of the statutory limitation (typically 2 years). Some would suggest that these records should not be destroyed because in the event of premature failure of a fabric filter (or process), the data preserved in these records could be used as an example of what not to do. On some fabric filters in service today, records going back 10 to 12 years have been kept to track the performance, cost, and system response to various situations and the most effective ways to accomplish things. These records serve as a learning tool to optimize performance and minimize emissions, which is the underlying purpose of recordkeeping. Some of these records may very well be kept throughout the life of the equipment. After several years, however, summaries of operation and maintenance activities are more desirable than the actual records themselves. These can be created concurrently with the daily operating and maintenance records for future use. If needed, actual data can then be retrieved for further evaluation.

SECTION 4

PERFORMANCE EVALUATION, PROBLEM DIAGNOSIS, AND PROBLEM SOLUTIONS

Many facilities that have installed fabric filters have done so with expectations of high collection efficiency, reasonable energy requirements, good long-term performance with reasonable bag life, and low maintenance requirements. Unfortunately, failure of the equipment to meet these expectations (because of poor design and installation, inadequate maintenance, or operation that is inconsistent with design constraints) often results in noncompliance and/or maintenance problems. Personnel responsible for evaluating the performance of a fabric filter should be familiar with the equipment design, the principles of operation, the importance of certain process parameters and their effect on performance, and maintenance requirements. This section presents discussions on the use of key parameters in monitoring performance, diagnosing or troubleshooting problems, and providing corrective actions for the most common problems. Because fabric filters are applied to a wide variety of sources, site-specific factors play an important role in the overall performance of these control systems.

4.1 PERFORMANCE EVALUATION

As discussed in Section 3, several key operating parameters should be monitored and recorded to alert operators to current performance conditions. To be of greatest value, however, these parameters must be compared against initial design conditions or baseline values to determine their acceptability. For example, measurement of temperature and pressure drop, two of the more common parameters, has little meaning if the design and baseline values of these parameters are not known. The temperature limits may be set by dewpoint conditions and by bag type, both of which are part of the design and baseline criteria data set. Without these data, the value recorded for temperature has relatively little meaning. A similar case can be made for pressure drop. Thus, a comparison of the key operating parameters with design or baseline values provides an awareness of what values are "normal" or fall within the range of acceptable performance.

Although a single data set is useful for evaluating operating conditions and performance, it generally cannot be used to evaluate trends in the fabric filter performance. Evaluating long-term performance, minimizing maintenance costs, and providing optimum bag life require the maintenance and evaluation of daily records so that any sudden or gradual changes in the parameters can be determined. Key process and control equipment operating parameters are, of course, of greatest interest in such an evaluation. With fabric filter systems, the parameters that should be reviewed to determine trends are opacity, pressure drop, temperature, pressure drop and temperature cycles (if continuous strip chart recorders are used), and such key process parameters as production rate. Fan speeds and motor currents also could be included in this evaluation. When evaluated in light of the gas temperature, the fan speed and motor current can be indicative of the gas volume moving through the system. Maintenance records are also very useful in evaluating long-term performance, in establishing performance trends, and in identifying failure patterns. For example, records of bag failures, their location, and the type of failure could reveal a design or operating problem when used in conjunction with daily operating records. How the records are arranged and what data are included are site-specific decisions.

4.2 DATA COLLECTION AND COMPILATION

For most fabric filter applications, the two most useful operating parameters are the opacity and the pressure drop across the filter material. In some applications, temperature data will be important for evaluation of the impact of high temperature excursions or condensation. The frequency for collection of these data will depend on several factors, but as a general rule, these data should be checked once a day. Continuous strip-chart recorders for opacity, pressure drop, and temperature can be very useful for indicating daily trends. The use of continuous strip-chart recorders is often limited to larger sources, however. Opacity monitors also tend to be used only in certain applications and at large industrial sources. Most small sources that use fabric filters have no opacity monitors. All sources, however, have means of monitoring temperature, and when fabric filters are applied to high-temperature sources or in situations where temperature problems may occur, the inlet gas temperature should be monitored continuously.

In the absence of continuous monitors/recorders, visible emission characteristics and onsite instrumentation must be observed periodically and the results evaluated. Opacity observations are very useful at most applications because opacity plumes at a properly operated and maintained fabric filter are generally very low, except when a condensible plume is present. A relatively continuous elevated opacity level can be indicative of the presence of major leaks and tears in the filter bags. Pinhole leaks are also usually discernible by an increase in opacity after cleaning of the bag(s). These kinds of plume characteristics are generally discovered by continuous observation of the plume as opposed to once every 15 seconds as required by EPA Reference Method 9. Whereas the use of Method 9 for determining average opacity is sufficient for enforcement purposes, changes in opacity that result from minor leaks may be missed when this method is used. In general, continuous observation of the plume to note any changes is better suited for evaluating maintenance requirements, as problems in certain rows or modules can be identified by this method.

The pressure drop across the fabric filter gives an indication of the resistance to gas flow and cleaning effectiveness. The pressure drop usually varies with the square of the gas volume flow through the fabric, but it will also vary with the thickness of the dust cake and the amount of material permanently retained by the fabric filter. This value will depend on various factors. The pressure drop of a fabric filter, however, generally falls within a "typical" range, and it is this range that is important. The recorded value should fall within the general operating range for the unit. Any changes in the pressure drop, whether gradual or sudden, may indicate the need for maintenance. If the cleaning cycle is initiated by a specified pressure drop, however, the pressure drop will not change, but the time between cleaning cycles will be shortened. When a large number of fabric filters must be evaluated, forms may be printed that include the typical or baseline values so that an immediate comparison can be made. For large, multicompartmented filter systems, recording the pressure drop across individual modules may not be necessary because pressure drop tends to equalize across all the modules.

For those units on which operating temperature is of particular concern, the use of continuous strip-chart monitors is highly recommended. Sometimes bag damage is not evident until days or weeks after a temperature-related incident. This can be troublesome to maintenance personnel because failure to detect the cause of deteriorating bags can result in unusually high maintenance costs. Although both inlet and outlet monitors are recommended, measurement of only the inlet gas temperature is usually sufficient. Temperature readings recorded during the acquisition of other data (opacity, pressure drop, production rate, etc.) are usually of little use by themselves, since they are not continuous.

Maintenance records are also useful in evaluating fabric filter performance. A record of bag failures and/or bag replacement can be especially helpful. In a typical application with newly installed bags, random bag failures shortly after startup is not uncommon. These are usually caused by an occasional defective bag and by installation problems. After these failures occur during the shakedown period, bag replacement requirements are expected to be minimal until the bags near the end of their useful lives. Records of bag replacement location, however, may reveal the presence of failure patterns resulting from design or operating practices. The existence of such a pattern may suggest a possible cause and solution that will improve performance and reduce maintenance costs in the long run. A typical bag replacement record is shown in Figure 4-1.

Another characteristic that bears examination is the physical property of the dust and any associated changes that may have occurred. Although site-specific factors control the characteristics of the dust to be controlled, two general characteristics that can influence fabric filter performance are particle size distribution and the adhesive characteristics of dusts. Changes in particle size distribution may increase abrasive wear if the particles increase in size. On the other hand, a shift to a smaller particle size range may increase penetration (bleed-through) and blinding. Changes in process operating characteristics can sometimes cause significant

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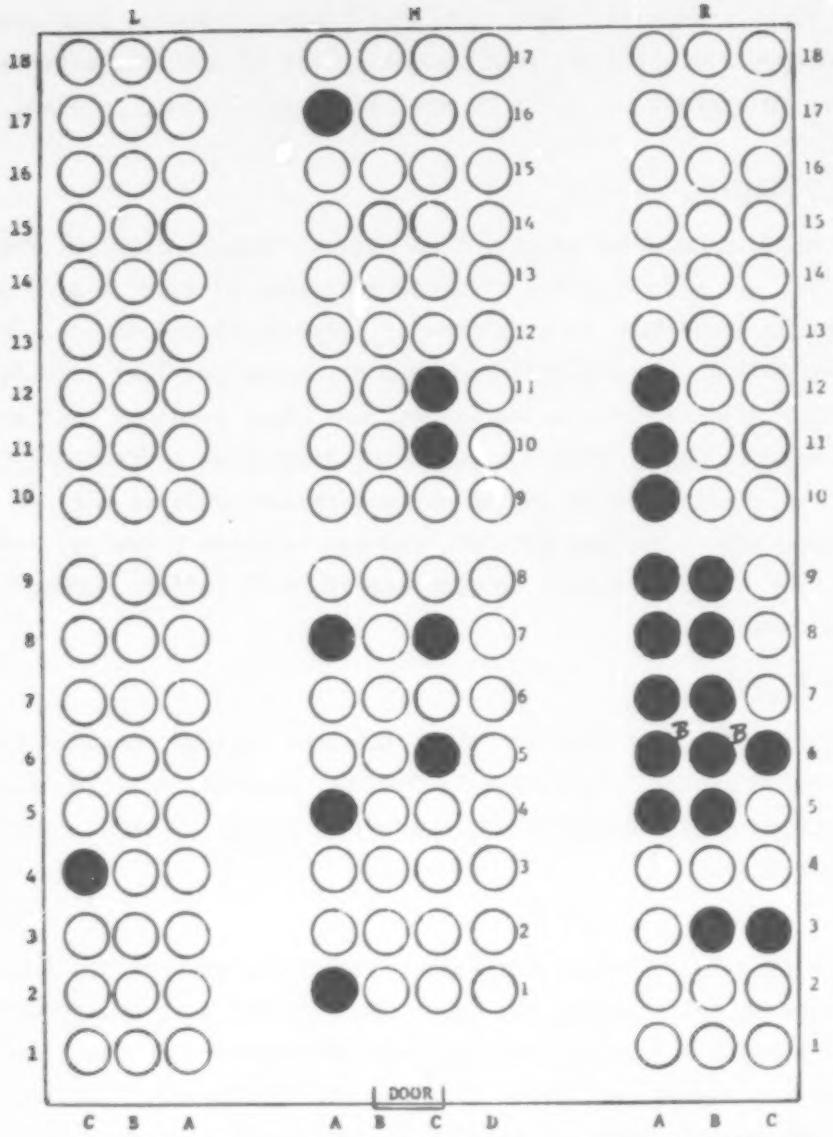

Key: B - Broken/Hole
No Letter - Ring
C - Collapse

Figure 4-1. Typical bag replacement record.
(Courtesy of Mikro-Pul Corp.)

shifts in particle size. Changes in adhesive characteristics can also result from variations in process operation conditions (e.g., some combustion sources can produce "sticky" carbon particles if combustion characteristics are poor) or fluctuations in temperature that produce dewpoint problems. Where such changes are possible, routine monitoring of dust characteristics may be prudent to prevent excessive or unexpected maintenance problems.

4.3 PROBLEM DIAGNOSIS

The two major categories of operation and maintenance problems are 1) problems that can affect fabric filters regardless of type, and 2) problems that are characteristic to a particular cleaning system design. The first category includes fabric failure, dust discharge problems, corrosion, poor or improper maintenance considerations, and other problems that are common to nearly all fabric filter types. The discussion of problems in the second category is presented by system design--shaker, reverse-air, or pulse-jet. Some hybrid systems will not conform to these criteria, and site-specific design factors must be considered. Most failure modes, however, are addressed here.

4.3.1 Fabric Failures

The factors that contribute to fabric failures include improper installation, high temperatures, condensation, chemical degradation, high air-to-cloth (A/C) ratio, high pressure drop, and bag abrasion. Each of these is discussed separately.

Installation--

The first step in achieving the expected performance from the fabric filter is proper installation of the bags in accordance with the guidelines provided by the bag manufacturer and the equipment vendor. Because these guidelines are not always available to maintenance personnel, training of maintenance personnel in proper installation procedures is very important. Reasons for lack of training vary, but generally they result from lack of vendor-supplied training and maintenance manuals and turnover in maintenance personnel. The latter creates a situation that necessitates almost continual training. Common problems resulting from improper installation of the bags include leaks around seals, improper bag tensioning, and damage to the bags during handling.

Failure of a few new bags is to be expected in a new or rebagged fabric filter, even during normal operating conditions, as a result of occasional manufacturing defects and improper handling during installation. After these few initial failures, however, if the system is properly designed and operated, the occurrence of such failures should be at a very low level until near the end of the bag life, when failures are likely to start increasing. If installed improperly, however, bags may continue to fail long after the initial installation and long before they approach the end of what should be their normal life.

To some extent, the design of the fabric filter can influence the extent of bag damage during installation. Systems that provide good access and are designed with maintenance considerations in mind reduce the likelihood of bag damage. The poor access design of a reverse-air fabric filter (see Figure 4-2) is not conducive to proper installation and maintenance. Examples of designs that facilitate bag replacement or installation are in pulse-jet systems with top-loading bags or reverse-air or shaker systems with a maximum "bag reach" of two or three bags. These designs allow maintenance personnel to disturb only a minimal number of "good" bags. Obviously, little is gained if the replacement of one or two bags results in the damage and life-shortening of several others.

In reverse-air and shaker-type fabric filter installations, damage often occurs when the bags are being hung. Access to the bag support and tensioning mechanisms may be difficult and cumbersome, and personnel may prefer to hang all the bags at once and then attach them to the tube sheet after all of them are suspended. The tendency, however, is to tie the bags out of the way as they are hung in the enclosure. (See Figure 4-3). Some fabric types can withstand this treatment with few problems, whereas others (most notably fiberglass) cannot. If the fabrics have poor abrasion resistance, tying the bags can cause leaks to occur wherever a crease is formed. Efforts should be made to tension these bags properly as they are installed, as this adjustment is sometimes difficult after all the bags have been hung. Care also should be taken to avoid stepping on the bags as they are taken out of their cartons or when they are laid on the floor prior to installation.

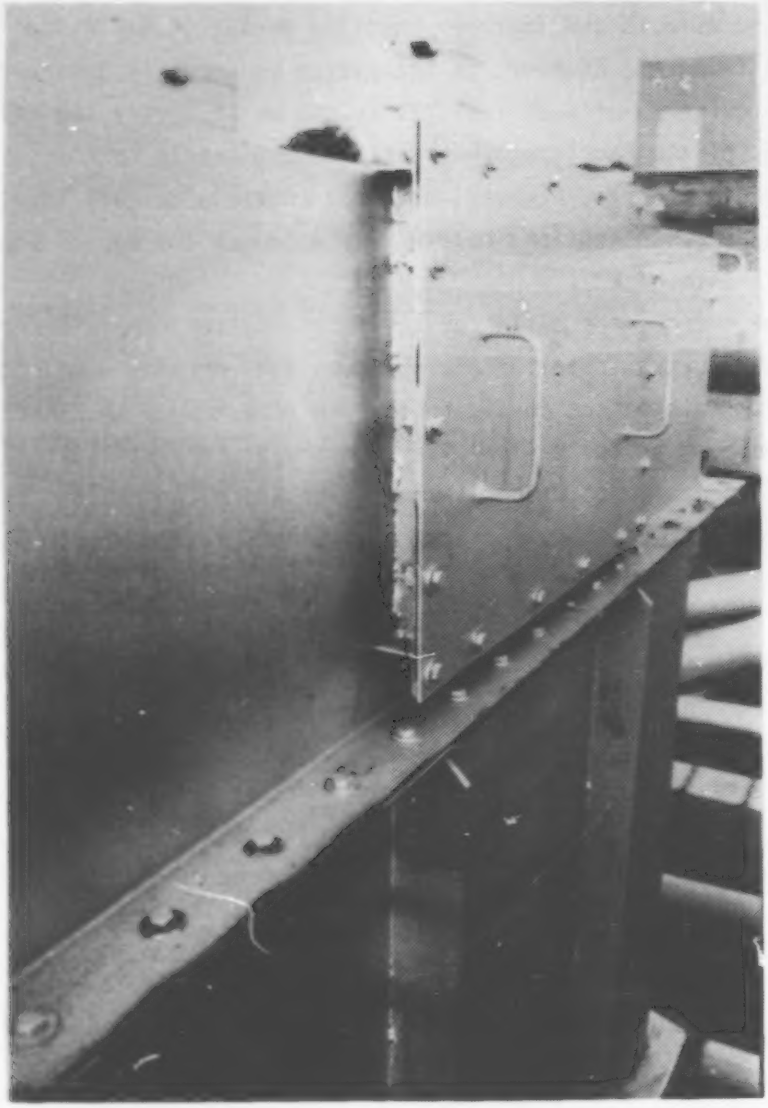

Figure 4-2. Example of exceptionally poor access to the top of a pulse-jet fabric filter. (The bolts on the bottom of the door cannot be easily removed because access to the nuts is blocked by the tubesheet; also, there are no ladders or walkways to this door.) (Courtesy of PEI Associates, Inc.)

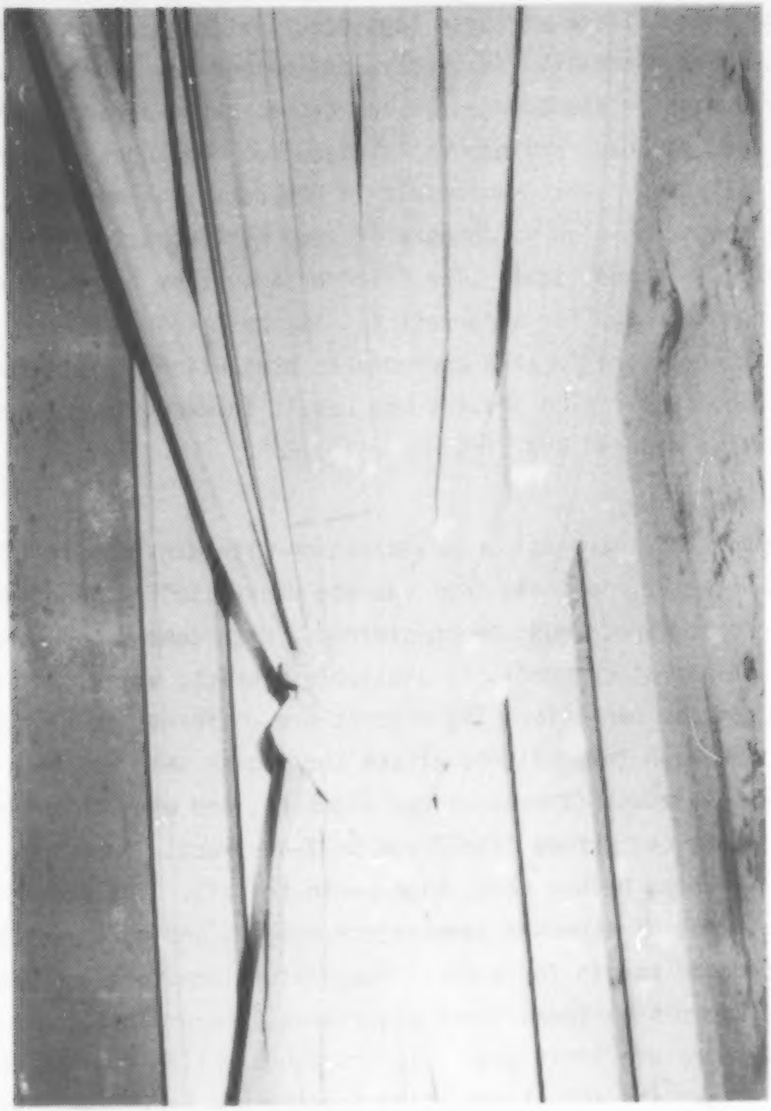

Figure 4-3. Tied-off fiberglass bags during bag replacement. (This may result in damage to new bags during installation.) (Courtesy of PEI Associates, Inc.)

Fabric filters with pulse jet cleaning systems (or any other design where filtration occurs on the outside and a cage is used for bag support) generally have shorter bags, which are a little more manageable. Most of the damage during installation of these bags occurs when they are placed on the cages. These bags generally fit snugly, and damage may result from improperly sized bags or sharp edges on the cages. When a number of bags are being installed, the bags are generally placed on the cages and stacked prior to their installation. This can result in bag damage unless special care is taken. These bags can also be damaged if they must be slid through a tube sheet and the fit is too tight. The "nip" or amount of the bag that can be drawn away from the cage for a correct fit is about 1/4 inch.

In summary, failure to take appropriate precautions to safeguard the bags during the installation process may result in excessive maintenance due to bag failure or reduced bag life.

High Temperature--

High temperatures are not a consideration with many fabric filter applications; however, in those that operate above 150°F, the effects of temperature on the fabric must be considered. High temperature breaks the polymer chains in most commercially available fabrics, which causes loss of strength and reduces bag life. The effects are different on high-temperature fiberglass. The high temperatures attack the finish that has been applied to the fiberglass to reduce fiber-to-fiber abrasion, and when this finish is destroyed, the bag can abrade itself and self-destruct. Sometimes it takes several days or weeks before these bags begin to fail. The fabric type is chosen on the basis of expected temperature ranges, and care must be taken to provide an adequate margin for error. Temperature monitors and alarms are often used to avoid high temperature excursions. Excursions above the recommended temperature limit generally shorten bag life considerably; however; the closer the actual operating temperature is to the fabric's temperature limit, the shorter the bag life will be.

Condensation--

Condensation of moisture and/or acid gases is generally associated with reduced temperatures within the fabric filter. Condensation of moisture or acid mist on the bags tends to alter the adhesion characteristics of the dust cake on and within the fabric structure, and "mudding" or blinding of the bags may occur because the cleaning system cannot remove this dust. This usually increases the pressure drop, and more fan energy is required to overcome the added resistance through the dust cake. Such conditions may occur near the walls of the unit when warm, moist, or acidic gases pass through a cool or cold fabric filter that has not been preheated. (For example, it is often advisable to preheat the fabric filter unit at an asphalt plant prior to introducing wet aggregate to the dryer.) Condensation may also occur if moist gases are not purged from the unit before it is shut down. When the temperature is allowed to cool below the dewpoint at the end of a production run, moist or acidic gases should be purged to prevent condensation on the walls and the bags within the fabric filter.

Chemical Degradation--

Chemical resistance refers to the fabric's ability to withstand acidic or alkaline conditions. Fabrics are rated according to their chemical resistance, but care must be exercised with regard to these classifications because certain fabrics are more susceptible to some chemical species than to others. Fiberglass bags generally are rated as having good acid resistance; however, the use of fiberglass bags in atmospheres with appreciable quantities of hydrogen fluoride would not be advisable. Nomex® is generally rated as having fair acid resistance. It is also generally known for its good moisture and SO_2 resistance; when both water and SO_2 are present, however, sulfurous and sulfuric acid mist is formed, the aramid structure of Nomex is attacked, and the fabric loses its strength. Individually, water vapor or SO_2 does not present a problem to Nomex, but in combination they can result in costly bag failure.

High A/C Ratio--

High A/C ratio generally results from an increase in gas volume moving through the system or the installation of an undersized system. The cleaning system type generally controls the range of acceptable A/C ratios; the lower-energy cleaning systems (reverse-air and shaker) use lower A/C ratios. Other factors, such as dust loading and particle size distribution, also influence the design A/C ratio. In general, the higher the A/C ratio, the higher the operating pressure drop. Excessively high A/C ratios, however, can result in very high pressure drops, and bag abrasion is increased because the particles impact the bags at higher face velocities. Bag blinding or an increase in the residual dust loading after cleaning also may occur because both the increased pressure drop across the bag and the increased velocity allow dust to penetrate into the fabric, where the cleaning system is unable to remove it. This will cause a gradual increase in pressure drop across the bags. The net result is generally an increase in energy requirements to maintain gas flow and a decrease in bag life.

High Pressure Drop--

As noted previously, high pressure drop can be a symptom of high A/C ratios. It can also occur when the cleaning system fails or when little or no cleaning energy is supplied to remove the dust cake from the bags. The greater thickness of the dust cake increases the resistance to gas flow, which in turn is reflected as an increase in pressure drop across the bags. High pressure drop also can result from bag blinding or condensation in the bags. Although it is usually a symptom of some other problem, high pressure drop itself may cause other problems. First, the greater resistance to flow tends to decrease gas flow through the fabric filter and can lead to fugitive emissions from the emission source. An increase in expended energy is required to maintain gas flow. Second, the greater differential pressure between the dirty and clean side of the fabric provides a larger amount of energy to draw particulate matter into the weave of the bag, which can lead to more abrasion damage within the bag and shortened bag life. Lastly, a very high pressure drop (10 to 14 in.) may cause the bag to be unable to withstand the pressure differential and to tear at points where the bag's strength has been reduced. In most fabric filters, only a few affected bags can lower the pressure drop and allow significant quantities of gas to pass through the fabric filter untreated.

Although high pressure drop is usually a symptom of other problems and should be treated as such, it should not be ignored. Even if the related problem does not shut the fabric filter down, the high pressure drop will lead to higher energy costs, reduced bag life, and increased maintenance costs.

Bag Abrasion--

Bag abrasion may be caused by contact between a bag and another surface (e.g., another bag or the walls of the fabric filter) or by the impact of higher-than-average gas volumes and particulate matter loading on the bags. Bag-to-bag contact can be a problem in nearly every type of fabric filter if the bags are not installed properly. Such contact may eventually wear a hole in the bag, and the resulting jet of gas flow through the hole will gradually enlarge it. On bags that collect dust on the inside, a hole may cause a high-velocity jet to impinge upon an adjacent bag and also eventually wear a hole in it.

Blast plates or diffusers (and sometimes precleaning devices) are recommended for many fabric filters. The purpose of these devices is to reduce the quantity of large particles that strike the bags and, along with long thimbles on shaker and reverse-air systems, to help minimize the wear on the bottom of the bag. Because of their size and weight, these large particles have great inertia, which allows the particles to strike the bag at an angle and eventually damage the bags. These particles have a tendency to stratify in the inlet of the fabric filter because their inertia reduces their ability to follow gas streamlines. It is not unusual to find abrasion problems in the bags on the side opposite the inlet. On most bags the greatest abrasion occurs within 18 to 24 inches from the bottom of the bag. Diffusers, such as the one shown in Figure 4-4, tend to help reduce the problem, and the diffuser should be checked periodically for wear.

Holes in the bags usually cause an increase in opacity, if small particles are present, and they also may cause a reduction in pressure drop. Pinholes are usually covered easily by the dust cake; thus, opacity increases after the bag is cleaned. This increase in opacity is relatively short, however, and diminishes as the pinhole is covered again. Tears or holes in the bags may or may not be covered by the dust cake, depending on their size and the pressure drop across the bags. The opacity generally will not decrease quickly or substantially, however, because the hole(s) may allow a significant quantity of material to pass through the system. Thus, opacity can be an indicator of the relative magnitude of any holes formed by abrasion.

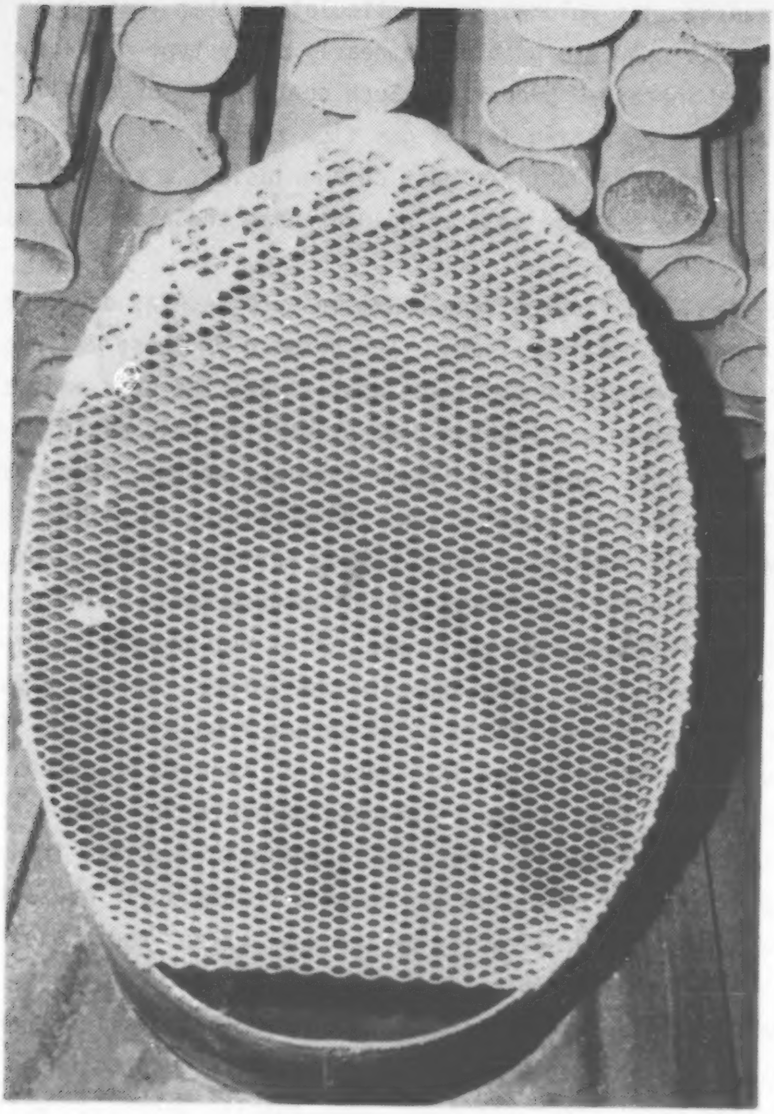

Figure 4-4. Example of a diffuser for deflecting large particles from the gas stream.
(Courtesy of PEI Associates, Inc.)

4.3.2 Dust Discharge Failures

Hopper pluggage can cause serious problems in a fabric filter. Regardless of the reason (cooling of the dust, inleakage, failure of the discharge system operation, or simply using the hoppers for storage), failure to remove the dust from the hopper usually results in having to open up the hoppers to clean them out. This can result in the type of fugitive emissions illustrated in Figure 4-5. The fugitive emissions generated by a single cleaning out of the hoppers may be greater than the emissions emanating from the fabric filter outlet for an entire year. Therefore, minimizing the occurrences of hopper pluggage by emptying hoppers continuously or frequently is very important.

Many dusts flow less easily when they are cold than when they are warm. Thus, insulation, hopper heaters, and continuous dust removal may be necessary to minimize the hopper pluggage problems. The effects of hopper pluggage are not always immediately obvious. As the dust builds up, dust resuspension may increase, as most fabric filter inlets enter through the hopper. This increase in resuspended material will increase the particulate loading on the bags, and it also may cause an increase in the pressure drop across the bags. When the dust buildup in the hoppers reaches a certain height, some bags may be partially or completely blocked from the gas flow, which increases the gas flow (A/C ratio) for the remaining bags and further increases the pressure drop. Eventually, all gas flow may be blocked from the hopper inlet. Dust buildup in and around the bags can be a problem, particularly as condensation occurs when the dust is cooled. This can lead to a condition similar to bag blinding.

4.3.3 Shaker Cleaning System Failures

Because gas flow from the fabric filter must be cut off before the shaker cleaning system can be operated, shaker-type fabric filters are either modularized or they are applied to intermittently operating sources where gas flow can be stopped so the shaking action can be effective. Several problems are characteristic of shaker-type fabric filters.

Shaker motors can be installed inside or outside of the fabric filter housing depending on the temperature and corrosive conditions in the gas

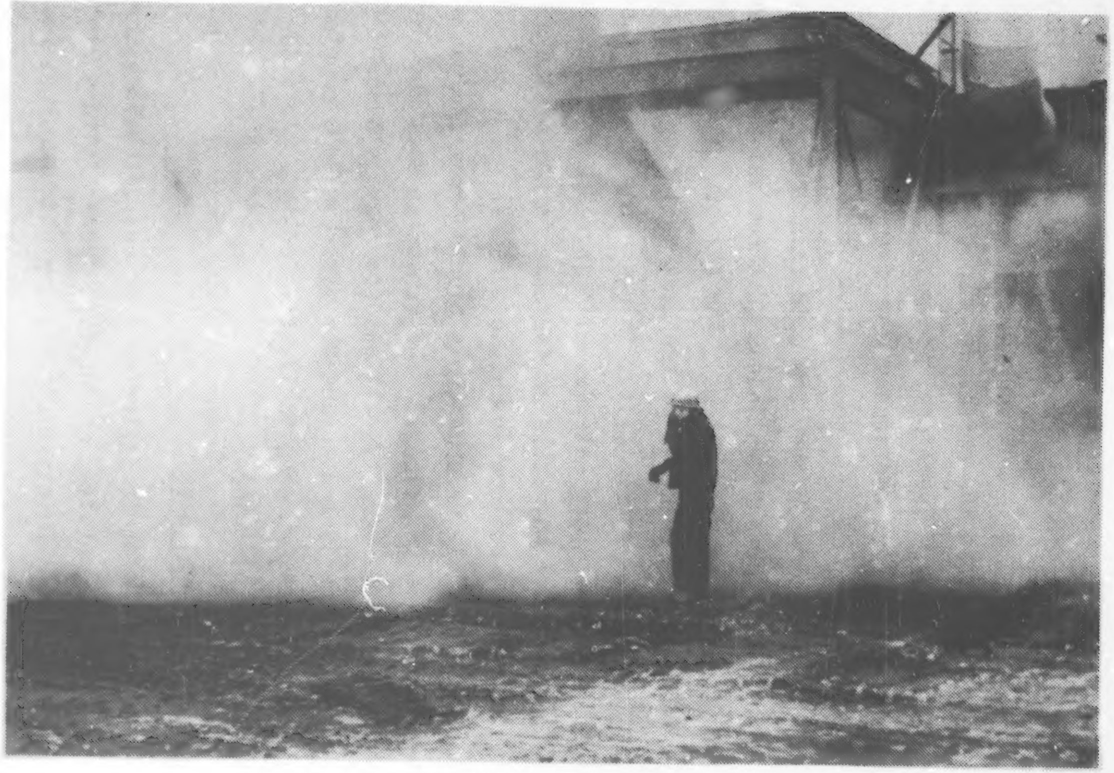

Figure 4-5. Fugitive dust emissions resulting from the opening of hopper access doors to clean out clogged hoppers. (Courtesy of PEI Associates, Inc.)

stream. These small motors (usually less than 5 horsepower) are usually installed outside the housing and are wired into a control circuit that may be manually or automatically activated. Operation of these motors is easily verified. The operation of internally mounted shaker motors, however, can be difficult to evaluate. Failure of the shaker motor may (and in many cases does) lead to excessive dust cake buildup on the bags and an increase in pressure drop. In some applications, when the gas flow is stopped by closing the dampers, the dust will slide off the bag. In most applications, however, the shaker system is needed for adequate removal of the dust and maintenance of a reasonable pressure drop.

The shaker linkages must be maintained in a manner that allows the energy provided by the shaker motor to be distributed through the shaking system to the bags. Because these systems are mechanical, periodic lubrication, checking for wear or loose parts, and replacement of broken parts are required to maintain their cleaning effectiveness. The only way to evaluate this system is to watch it in operation to ascertain that all the bags are being cleaned at approximately the same intensity. Watching the system operate may reveal that certain modules or certain shaker bars are not being moved through the correct amplitude. These sections have higher resistance to flow, and the gas is forced to flow through the bags having less resistance to equalize the pressure drop. Although the overall pressure drop may increase somewhat, abrasion and blinding damage may occur in the bags being cleaned more effectively by the shaker system.

The third problem in fabric filters with shaker cleaning systems concerns bag tension. Bag tension changes with the age of the bag and with the amount of material collected on the dust layer, and it is usually expressed in the number of pounds of force applied to the top of the bags. Thus, bag tensions are usually adjusted by some arrangement at the top of the bag. Bags that are too tight may not transfer the shaker energy effectively and may be damaged during shaking. Bags that are too loose may sag on the tubesheet, and bag abrasion may result from the bag being placed in the gas stream or being contacted by the thimble or other bags. Loose bags also may not use the cleaning energy effectively and may block the flow of dust out of the bags if they sag, fold, or close off above the tubesheet. Proper tension allows the dust to flow out of the bag without sagging problems or problems in the transfer of shaker energy.

Problems can occur in the bag hanging mechanism if bag tensioning is not proper. Some systems use chains or threaded bolts that attach the shaker bar to the top (metal cap) of the bag. In other cases, the bags have a tongue that is threaded through a clip, and friction is used to keep the bags on their hangers. Maintenance personnel must properly install the bags to ensure that they remain attached at the top and that they won't fall down or lie on the tubesheet. When fabric filters are used to control dense dusts (e.g., in the metals industries), the bags sometimes fall because they were installed improperly or because bag tension and/or cleaning efficiency were inadequate to remove the dust from the bags. When bags become heavily ladened with dust, they will pull away from the attachment mechanism or cause this mechanism to break. Because the bags that lie on the fabric filter floor are essentially out of service, the actual A/C ratio, the pressure drop, bag wear, and maintenance costs all increase.

4.3.4 Reverse-Air Cleaning Systems

Like the shaker cleaning system, the reverse-air system is a low-energy system that cannot function properly if gas flow is present in the module or area being cleaned. The damper systems for fabric filters with this cleaning mechanism tend to be more complex than those for the shaker system because a reverse flow of gas is used to collapse the bag, to break and release the dust cake, and to allow it to be collected and removed from the fabric filter. Failures in this type of filter system are most often related to the improper functioning of the cleaning system.

Several types of reverse-air cleaning system designs are available. Some use a separate reverse air fan, and others do not. Despite the particular design, the gas flow must be stopped in the module so that cleaning may take place. This requires a positive seal on the reverse-air isolating damper (a poppet damper is often used). Without proper sealing, the bags may not collapse properly and the cleaning action may be ineffective. Unlike the other cleaning systems, relatively little energy is available to clean the fabric, as the reverse flow of gas through the bags is usually small compared with normal, on-line gas flow. Over a period of time, the overall pressure drop will gradually increase because of buildup on the bags.

Failure of the isolation dampers is usually easily detected, as the actuators are generally pneumatically or hydraulically operated and the movement of the piston is visible. Too little movement of the piston usually indicates that the damper is not sealing properly. Symptoms of problems are similar to those for the reverse-air supply dampers. In some situations, the failure of the damper system can be detected by a missing spike and subsequent decrease in pressure drop after the affected module comes off line for cleaning. Moisture and oil in the compressed-air supply lines can cause blockage during freezing weather and result in the failure of these pneumatically operated systems. Damper operation failures, however, usually result from failures of the controlling timers or pressure drop sensors that are used to activate the cleaning cycle at certain intervals or at certain pressure-drop thresholds.

Buildup of materials around the dampers or deformation of the dampers or their seals can cause problems with proper isolation of a compartment for cleaning. Symptoms of this problem are similar to those for a malfunctioning damper system, and they may register on the continuous pressure drop recorder. The major difference is that the damper would appear to be functioning. Confirmation of poor damper sealing is only possible by internal examination of the equipment, and even internal inspection of the damper system may be inconclusive because the system must be cooled sufficiently for safe entry. An internal inspection, however, may indicate the presence of light leaks, warped dampers and seals, or buildup or wear of the dampers caused by material passing through the fabric filter. The damper operation and seal should be checked periodically as part of a preventive maintenance program.

Proper bag tension is essential to bag cleaning. Just as it was important for the bags to be properly tensioned for the shaking action to be effectively transmitted to the bag, attention to bag tension is necessary to obtain the proper collapse and flexing of the dust cake for its removal from the bags. Bags that are too tight may not collapse enough to allow effective flexing of the dust cake. Too much tension can also damage the fabric. On the other hand, insufficient tension of the bags may allow the bags to collapse to the point where the bag is closed down during the reverse-air cleaning cycle (even when anticollapse rings are used). Loose bags also may suffer abrasion due to the bag being sucked down into the thimble. It is recommended that thimbles be rounded and free of sharp edges to prevent tears if this should occur.

Proper bag tension is a function of attention to detail during the initial installation. Bags must be hung properly, without damage, if the proper life expectancy is to be achieved. Bag tension will vary with the age of the bag and also within any given cleaning cycle as material builds up on the bags. Poor bag tension can increase bag wear, cause high pressure drop, and shorten bag life.

Corrosion also can be a problem in this type of fabric filter. In some applications, most notably where acid dewpoint conditions have not been adequately considered, corrosion of the metal anticollapse rings has resulted in abrasion and wear of the bag at the site of bag ring contact as shown in Figure 4-6. Sometimes fuels or process parameters can be modified to reduce potential corrosion. Special alloy metals or coatings also can be used to minimize or eliminate corrosion problems.

4.3.5 Pulse-Jet Cleaning Systems

Pulse jet fabric filters are widely used because of their smaller size and because their higher available cleaning energy allows for higher A/C ratios. Despite the attractiveness of their lower initial costs, however, these bags have their limitations and potential problems because of the higher energy required to operate these systems.

The higher A/C ratios on this fabric filter type increase the potential for fabric abrasion. Therefore, greater efforts should be made to minimize other, often-overlooked, abrasion-related failures.

Typically, the bags in a pulse-jet fabric filter are suspended from a tubesheet and supported by a cage. This single-point method of attachment allows the bag to move around during normal operation. One source of bag abrasion is bag-to-bag contact due to improper installation, poor alignment of the bag/cage assemblies with the tubesheet, or bent/warped cages. The rubbing together of the bags (usually at the bottom) can wear a hole in one or more of the bags.

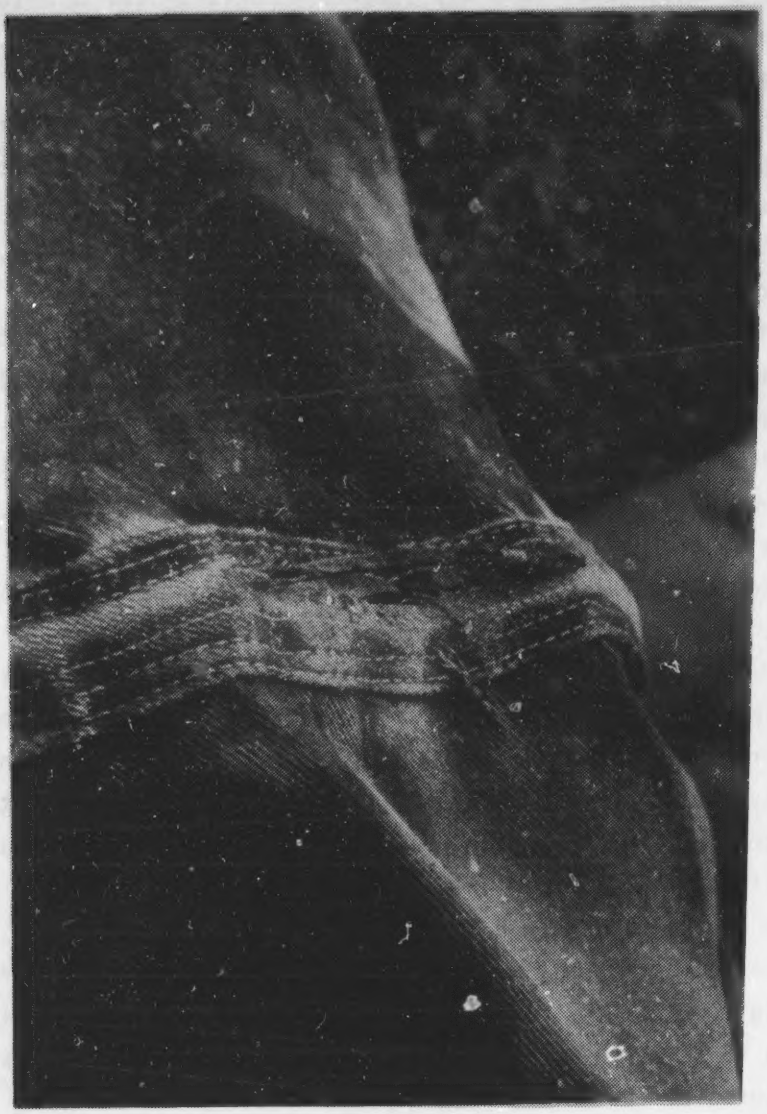

Figure 4-6. Example of bag wear caused by corrosion of metal anticollapse rings. (Courtesy of PEI Associates, Inc.)

The misalignment of bag/cage assemblies can also cause other problems. In some designs, the misalignment of the cage will prevent proper sealing of the bag with the tubesheet. This may allow some of the dust to bypass the filter area, which decreases performance but probably causes little or no change in pressure drop. Particularly abrasive dust has been known to wear the bags and the tubesheet so severely at the point of the leak that achieving an adequate seal may be impossible without replacing the tubesheet.

Another abrasion-related problem concerns the condition of any baffle or blast plate that may be installed at the inlet of the fabric filter. The purpose of this device is to "knock down" the heavier particles and to distribute flow such that the larger particles do not strike the bottom of the bags opposite the inlet. Not all designs are equipped with a blast plate, which should bring the gas flow below the bottom of the bags. When failure of the bags occurs within about 18 inches of the bottom on the side opposite of the inlet, the presence and integrity of the blast plate or diffuser plate should be checked. Although other problems with the cleaning system can lead to increased bag wear and poor performance through higher pressure drop, these problems tend to be more indirect in nature.

The design and operation of the pulse-jet system generally call for on-line cleaning, which requires the availability of considerably more cleaning energy to remove the dust from the bags (in addition to the higher A/C ratios normally encountered with this design). Failure to provide this energy will generally show up quite readily as an increase in pressure drop because a relatively small cloth area is handling a large gas flow. Several components can contribute to such a problem.

The compressed-air supply must be able to provide a pressure of between 90 and 120 psig to clean the bags effectively. Compressed-air requirements for short bags (6 to 8 ft) may be lower (say 60 to 90 psig); whereas for 14 ft bags, pressures of 120 to 140 psig may be necessary for adequate cleaning. The pressure must be high enough to clean the entire length of the bag during the pulse, but not so high that it damages the upper portion of the bag. Insufficient cleaning of the bag may gradually increase pressure drop and reduce the useful bag life. Too low compressed-air pressure, which is usually more common than excessive pressure, may be caused by wear of the compressor rings, leakage of diaphragms, or excessive draining of the reserve of the compressors by other equipment tied to a common supply line.

The leakage around a diaphragm, which can usually be detected audibly by the absence of the resounding "thud" that typically characterizes proper operation of the pulse-jet system, affects the cleaning effectiveness for all the bags. Although it may take several hours or several days, the pressure drop usually will increase eventually if the leak is severe enough.

Failure of the solenoid(s) or the timer circuit may cause one or more rows not to be cleaned. Effects on fabric filter performance may range from indiscernible to complete cutoff of gas flow, depending upon the percentage area of the bags affected and the dust characteristics. Both mechanical and electronic timers are still in use, and both have certain advantages and disadvantages. An electronic timer is shown in Figure 4-7; solenoids that are activated by the timer are shown in Figure 4-8. Both types must be kept in a dust-free, dry environment and relatively free from the shocks and jolts that can accompany normal operations. Solenoid failures affect the row that has experienced the failure whereas timer failures tend to affect most, if not all, of the fabric filter system.

When the timer activates the solenoid that opens the diaphragm at the end of the pulse pipe, the force of the compressed air entering the pulse pipe and discharging into the bags places considerable stress on the pulse pipe. In some instances, the force is sufficient to break the attachment at the other end of the pipe (usually a bolt and nut), which allows the pipe to bounce around inside the fabric filter when the row is cleaned. Several problems may result. First, the pulse pipe may not be properly aligned to provide effective cleaning to that row. Second, the alignment may be such that the pipe openings are aimed directly at the bags and can blow holes in them. Lastly, the loose pipe may damage the tubesheet or even the fabric filter enclosure, which would necessitate additional repairs. The sound of a loose pulse pipe is usually unmistakable, as it moves around whenever the pulse-jet compressed-air is fired into that pipe.

Although all of these problems are relatively common in most pulse-jet systems and may produce bag abrasion or shorten bag life, the one problem that seems to recur with greatest frequency is the presence of water and/or

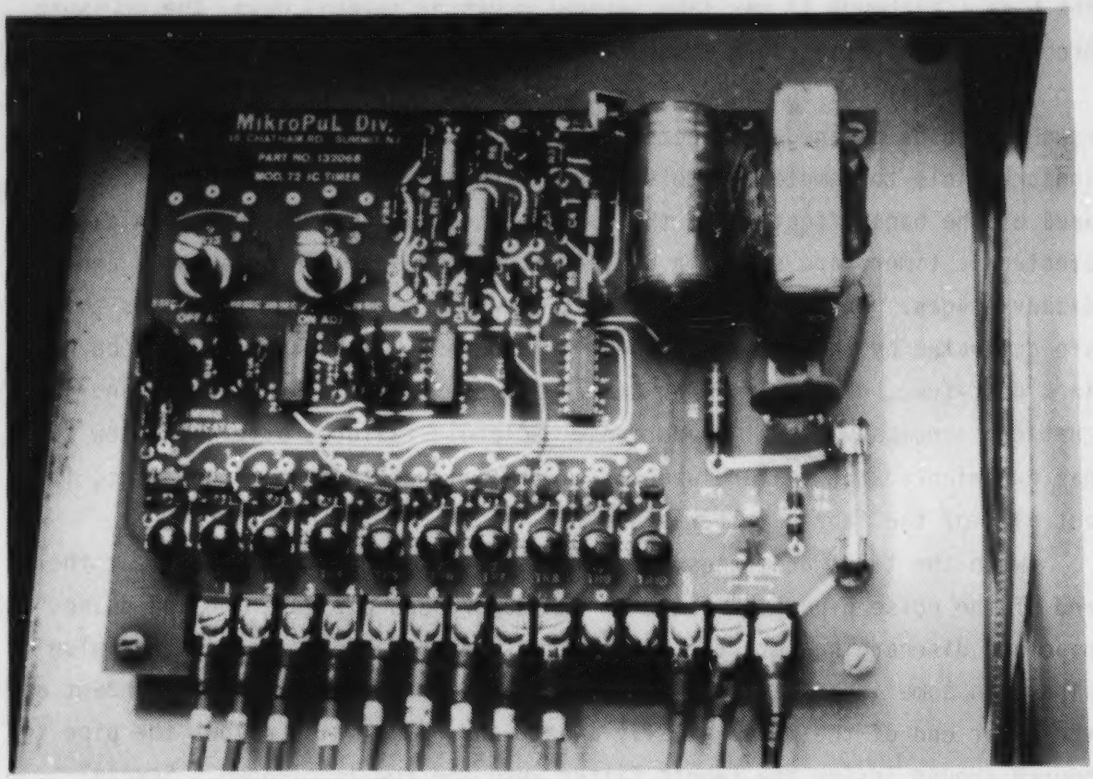

Figure 4-7. Electronic timer circuit board for a pulse-jet filter. (LED's at each position indicate when the circuit has fired a signal to open the pulse-pipe diaphragm.) (Courtesy of PEI Associates, Inc.)

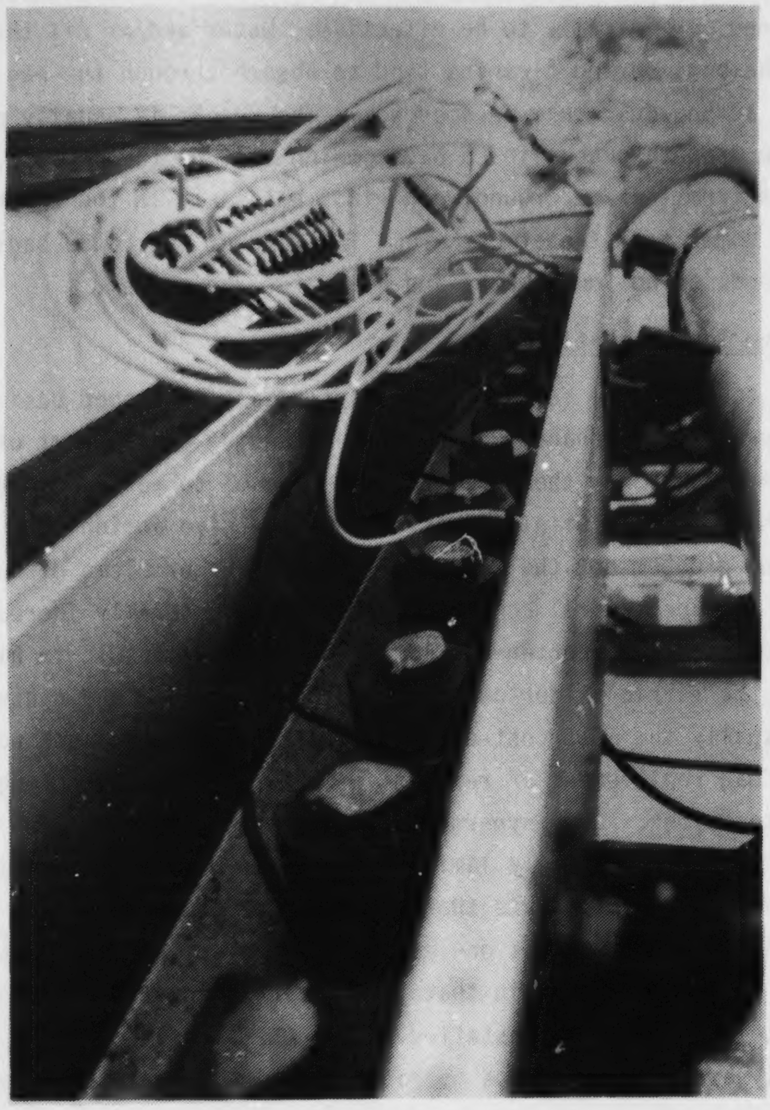

Figure 4-8. Pulse-jet solenoids for individual rows of bags.
(Courtesy of PEI Associates, Inc.)

oil in the pulse-jet compressed-air supply. Compressed-air systems can be equipped with small water and oil traps that work well if the compressor is maintained and the humidity is not excessive. Even these systems, however, must be drained periodically to be effective. Water and/or oil that are blown into the bags during cleaning tend to absorb through the bag and cause bag blinding as the dust cake becomes wet. The result is usually excessively high pressure drop through blinded bags, which must be thrown away. The oil usually comes from leakage around worn rings and seals in the compressor and the moisture comes from the atmosphere. The rate at which the bags are affected depends on how much water and oil enter the system.

4.3.6 Problem Identification

The key to effective fabric filter performance is a good design that facilitates proper maintenance, a good understanding on the part of maintenance personnel as to how the equipment is supposed to work and what can go wrong, and the existence of a diagnosis and corrective action plan aimed at correcting the problem not the symptom. Many of the problems discussed in this section produce several common results: they generally increase bag pressure drop, they may shorten bag life, and they may result in higher opacity from the fabric filter outlet. Trying to isolate the cause of the problem is usually the most cost-effective approach because such action may avoid costly bag replacement or repetitive failures that cause long-term performance to suffer. Some synergistic effects are possible with the fabric filter, but they are relatively limited in scope. Usually repetitive failures in a fabric filter indicate that the cause or causes have not been properly identified. Sometimes one must check the actual equipment against the original design to ascertain that the fabric is identical to that specified and that it is properly installed. When these questions have been satisfactorily addressed, various operating problems should be investigated.

4.4 CORRECTIVE ACTIONS

Fabric filters generally have a potentially high collection efficiency, but they must be maintained properly to achieve acceptable long-term performance. This includes preventive maintenance and the correct diagnosis and solution to problems as they occur. Some of the corrective actions are obvious. Even so, the bulk of the maintenance effort seems to be aimed at correcting the symptoms of problems rather than finding the cause and correcting it to avoid recurrence. For example, if a set of bags are destroyed by burning, they obviously must be replaced. That solves the immediate problem of high emission rates, but it doesn't answer the following questions. What caused the bag damage? Is there a high temperature alarm and recorder in the system? Does it work? Could this have been prevented, and can it be prevented in the future? Trying to find the cause of a problem and to correct that cause involves a different approach and attitude than simply treating the symptoms. This difference should be recognized by both plant and regulatory personnel. This section stresses how this difference can effect long-term compliance expectations and in some cases, control costs.

4.4.1 Fabric Failures

Installation--

Failure to install filter bags properly almost certainly guarantees future problems with the bags. For example, on pulse-jet fabric filters aligning and sealing the bag at the tubesheet are somewhat difficult tasks. In some applications (e.g., cement clinkers), the dust is very abrasive and will eventually wear away the tubesheet at points where the bag is not sealed properly. This can necessitate replacement of the tubesheet if the wear is so significant that the bags can no longer be sealed, even with extra effort and attention on the part of maintenance personnel. When this occurs, the lost production and equipment replacement costs are substantial as a result of a problem that could have been avoided had the bags been installed properly at the outset. Figure 4-9 demonstrates correct and incorrect methods of installing bags in a reverse air fabric filter.

A little more attention to detail and proper installation can often make the difference between good and poor performance and acceptable and unacceptable bag life.

High Temperature--

The effects of high temperature conditions can range from a few holes in the bags caused by sparks to complete destruction of all the bags resulting

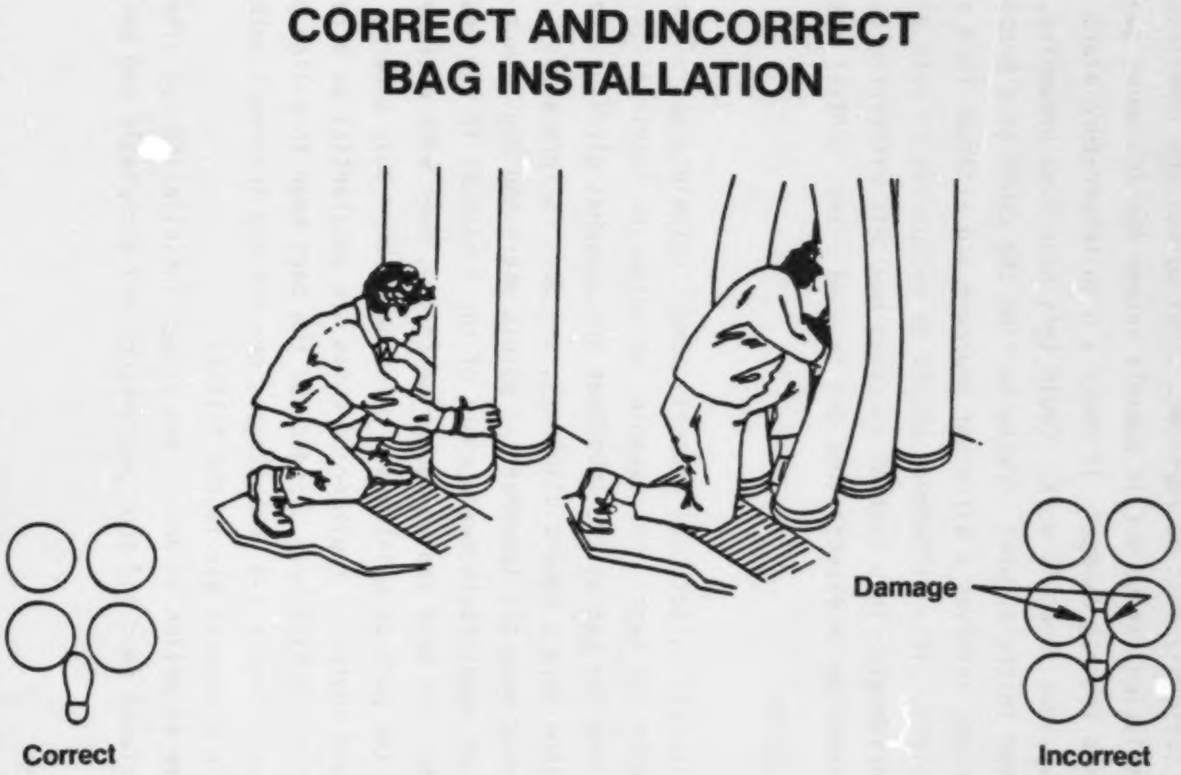

Figure 4-9. Example of correct and incorrect methods of installing bags in a reverse air fabric filter.
(Courtesy of Wheelabrator-Frye, Inc.)

from generally high temperatures within the fabric filter. Although damage from high temperatures is usually limited to sources operating at elevated temperatures, it cannot be ruled out for sources where spark carryover into the fabric filter is a potential problem. For example, in the furniture and woodworking industry, fabric filters applied to sanders and abrasive planers have the potential to throw a spark into the gas stream that may then be carried to the fabric filter. The ensuing fire or explosion will destroy the bags just as surely as if the air temperature had been raised over the bag temperature limitation. The use of temperature monitors is usually recommended at sources that operate at elevated temperatures, and plant personnel generally install alarms and perhaps an emergency bypass system to protect the system from temperature excursions. A temperature monitor would be useless in the example cited above, however, because the temperature sensor would not react quickly enough to take action to avoid the situation. Spark arrestors have been used with some success where sparks (not high gas temperature) have proven to be a problem.

When high temperature damage to the bags does occur, the cause of the temperature excursion (e.g., operator error, process upset and nature of upset) should be determined and action taken to prevent the occurrence of the problem. This might entail the installation of temperature recorders where none existed previously, the addition of temperature-conditioning systems or an emergency bypass, education of operators to avoid certain conditions, or combinations of conditions that may lead to high temperature excursions. Proper identification and correction of the cause of high temperatures usually prove to be much less expensive than periodic replacement of the bags.

Condensation--

The condensation problem can generally be corrected by increasing operating temperature, decreasing moisture and/or acid gas levels entering the fabric filter, or by insulating the fabric filter more effectively (if insulation already exists). Removal of the gases prior to shutdown and preheating the fabric filter before startup (usual purge and preheat times range from 5 to 20 minutes) also may minimize the potential for condensation within the fabric filter. All of these points could be considered as changes in operating practice.

When a fabric filter already has a bag blinding problem as a result of condensation, little can be done but change the bags and try to avoid a recurrence of the conditions that caused the problem. In some situations, allowing the bags to "dry out" by passing hot, dry gas through the system, may enable the cleaning system to remove enough material for the fabric filter to become operational again. Some permanent increase in pressure drop is likely to remain in this situation, however, which means increased energy cost to the plant and potentially shortened bag life.

Another option that has been used with some success is to remove and wash the bags and then place them back in service. The cost varies according to bag size and construction, but it generally runs approximately half that of the cost for new bags. The bags are removed from the fabric filter and checked individually and the integrity of each is checked. Only those bags that appear to be in good condition are washed or dry-cleaned; other bags are replaced. Before being placed back in service, the cleaned bags are again screened to check for fabric integrity. Those bags that do not pass must also be replaced. For bag washing to be effective, only a small percentage of bags (i.e., less than 10%) can be rejected during the screening process and at least half of the expected bag life must remain. Otherwise, bag washing or dry cleaning does not appear to be a cost-effective approach.

When the particulate matter to be captured by the fabric filter is expected to be sticky or condensible material, a precoating may be injected into the gas stream to coat the bags and keep this sticky material from condensing on or in the bags and blinding them. Any dry, powdered inert material may be used, but pulverized limestone is the most common. This material must be added continually to protect the bags. When limestone is used, care must be taken to prevent temperatures from falling below the moisture dewpoint. Otherwise, the limestone will "set" and blind the bags. Fly ash and other materials have also been used for precoating the bags.

Chemical Degradation--

Bags damaged by chemical degradation generally must be replaced. Once begun, loss of fabric strength due to chemical degradation cannot be reversed. After the damaged bags are removed, consideration should be given to altering the temperature (if condensation or increased degradation is occurring at current conditions), to removing or reducing the offending constituent, or to changing to a less susceptible fabric. If chemical degradation is occurring near cool surfaces in the fabric filter, improving the insulation or installing windbreaks may help to correct localized chemical degradation problems.

High A/C Ratio--

When high A/C ratios are known to be a problem, the two most viable solutions usually are to reduce the gas volume through the system or to increase the filter area by installing additional fabric filtration capability. The costs of operating a system at a higher than normal design range of A/C ratios are generally related to the energy required to move the gas through an increased resistance (pressure drop), and the increased bag replacement costs resulting from bag abrasion, blinding, and generally shortened bag life. In some situations, the cost of operating and maintaining the system at high A/C ratios far outweighs the cost of adding additional filter area or finding ways to reduce the gas volumes through the fabric filter system. This is particularly true when the fabric filter is applied to a combustion source. Combustion and thermal efficiency are related to the amount of excess air used in the combustion process. In a boiler, for example, the thermal efficiency decreases as the percent excess air increases. Thus, for a given boiler operating at a fixed steam production rate, more fuel is required per pound of steam at higher excess air conditions than at lower excess air conditions because of changes in thermal efficiency. The net result of burning more fuel at higher excess air levels is an increase in the quantity of flue gas produced and, therefore, an increase in A/C ratio. This in turn produces a higher pressure drop across the fabric filter and the potential for bag damage and shortened bag life. Energy costs alone are usually substantial enough to merit changes in the operation of the unit, but personnel must look beyond the symptoms to the causes and evaluate what can be done to improve performance and reduce costs at the same time.

High Pressure Drop--

Because, as stated earlier, high pressure drop is usually a symptom of some other problem, personnel must seek the cause of the problem within the system.

Bag Abrasion--

Like high pressure drop, bag abrasion is often a symptom of a problem elsewhere in the system. Causes of bag abrasion include bag-to-bag contact, poor tensioning of bags, lack of or wear of a baffle plate or other precleaning device, short or no thimbles (in some shaker and reverse-air systems), and high pressure drop as a result of high A/C ratios or bag blinding. All of these problems are related to installation, design, or operating problems, most of which are discussed elsewhere in the manual.

If the fabric filter includes precleaning devices and blast plates, these should be checked periodically for wear, as they can wear out quite quickly and allow carryover of heavier, more-abrasive particles to the fabric. When wear of the bags opposite from the inlet is consistent in fabric filters not equipped with blast plates or long thimbles, equipping the fabric filter with a method for protecting the bag may be worthwhile. For bags mounted on thimbles, the thimbles should be well-rounded with no sharp edges and the bags should be properly tensioned. Again, determining the cause of the bag abrasion rather than just replacing the damaged bags may ultimately save maintenance time and money.

4.4.2 Dust Discharge Failures

Hoppers should not be used for long-term storage. Actually, continuous removal of dust from the hoppers is preferred to minimize compaction and hopper bridging. At sources operating at elevated temperatures, this can be particularly important because many dusts have better flow characteristics when they are warm than when they are cold. To assist those persons assigned to check the equipment periodically, markers should be placed on the shafts of the dust discharge system for easy confirmation that the equipment is operating.

Dust discharge systems must maintain a seal in negative pressure applications. If the fabric filter is located ahead of the fan, the system will most likely be under negative pressure. The hopper, dust discharge, and airlock system should be free of air inleakage to reduce or eliminate the resuspension of particles into the gas stream, and at sources operated at elevated temperatures, to reduce the cooling effects attandant with inleakage. If hopper pluggage is due to cooling of the dust, eliminating inleakage, installing proper insulation, and using hopper heaters are possible corrective alternatives. This assumes that the dust discharge is adequately sized. If such is not the case or if particle characteristics change, the system may be unable to handle the quantity of dust delivered.

Vibrators can sometimes cause further compaction of the dust in a hopper rather than helping the dust flow, which should be considered in a decision of whether to use a vibrator. The use of a sledge hammer by plant personnel also should be approached carefully. In some situations, beating on the hopper only compacts the dust and puts dents in the hopper that provide future sites for further hopper pluggage. Taken to extreme, the hoppers can become so distorted that they remain constantly plugged or holes form that allow inleakage or fugitive emissions, depending on how the system is designed.

In all cases, hoppers should be cleared as soon as possible to prevent bag blinding, to avoid damage to the dust conveying system, and to minimize the fugitive emissions generated by manually emptying the hoppers.

4.4.3 Shaker Cleaning System Failures

When a system or module is isolated for cleaning, there should be no flow of gas through the system. Although damper activation can usually be checked visually during operation, the integrity of sealing cannot. Depending on the damper and fan arrangement of the system, a pressure differential across the module should show either a zero pressure drop or a static pressure equal to the outlet value. If the value measured for the isolated compartment varies from these values, some gas is still flowing through the compartment. This can make the shaking action less effective in removing the particulate matter from the bags, and bag blinding and higher than normal pressure drops may result. Although shaking action can be intensified somewhat to counteract the less effective cleaning, such action could damage the bags.

Shaker motors and shaker mechanisms should be kept in good operating condition. They should be checked periodically as part of a preventive maintenance plan, and any broken or worn parts should be replaced.

Bag tension and bag suspension should also be checked periodically. New bags may stretch or shrink when exposed to the gas conditions in the fabric filter. Approximately 2 weeks after initial operation, new bags should be checked for proper tension and adjusted as necessary. It should be noted that the tension on the bag will vary with dust cake loading. It is probably better to shake all the bags so that some valid comparison of tension can be made before adjustments are made. Records should be kept of the adjustments made and the observed dust cake release to determine if any trends or patterns are occurring.

4.4.4 Reverse-Air Cleaning System

Failures of the reverse air cleaning system are usually related to poor bag tension, failure of isolation dampers, and failure of the reverse-air fan(s). As in the shaker type fabric filter, isolation of the module being cleaned is essential for proper operation. It is not the reverse flow of gas that removes the dust from the bag, but the flexing action of the bag itself. Failure of the cleaning system to work in a coordinated action tends to leave an excessive dust cake on the bags, a higher pressure drop, greater bag abrasion, and possibly reduced bag life.

Failure of the reverse-air fan would allow the bags to hang in the fabric filter when the compartment is isolated, but no energy would be applied to flex the bags, so excessive dust cake buildup eventually occurs. The fan should be periodically checked for proper operation, and on some larger systems, the reverse-air fan motor current should be monitored to ensure proper operation.

Failure to seal the isolation dampers or open the reverse-air damper can present problems. On most systems the damper drive systems (pistons, etc.) can be visually checked. In many cases, however, confirmation that the dampers are fully closed and sealed is not possible. If monitored, pressure drop across the tubesheet during the "dwell" period should show 0 in. H_2O because the gas flow through the compartment would ceas[illegible] If the manometer is working correctly and some pressure drop is observ[illegible]e could conclude that the dampers were not sealing properly, and mai[illegible]ance should be scheduled to adjust or repair the dampers.

Bag tension should be checked periodically, particularly after bag replacement. Approximately two weeks after replacement, the tension should be checked and adjusted as necessary. Because dust layer thickness may affect bag tension, the tension on all bags should be compared after cleaning so that proper tension is provided. Excessive buildup in the bags should be noted, recorded, and evaluated for trends or patterns within the fabric filter.

4.4.5 Pulse-Jet Cleaning System

As discussed earlier, problems with pulse-jet systems that involve bent cages, leaks in bag/tubesheet seals, and bag-to-bag contacts primarily result from improper installation. This difficulty can be eliminated through proper training of personnel responsible for bag installation. Bag abrasion resulting from wear or lack of a baffle plate have also been discussed. The corrective actions discussed in this subsection focus on the compressed-air system.

The compressed-air pressure must fall within a specific range to generate a shock wave that traverses the bag length and returns, and thereby flexes the dust cake and causes its removal from the bag. The pressure range is partially related to the length of the bag; higher pressures are required for longer bags. If pressure is insufficient, the bags will not be cleaned properly and pressure drop will begin to rise. Insufficient pressure conditions can result from an undersized compressor, a leak in the system, a large number of systems being served by the compressor at one time, or someone's closing a supply-line valve. If the compressor is inadequate to handle all the needs of the various systems, additional compressor capacity may be required. The cost of extra compressor capacity would be offset by lower energy costs resulting from the fabric filter operating with cleaner bags. The various systems supplied by the compressor(s) also should be checked to ensure that no leakage or otherwise wasteful use of compressed air is occurring. For example, a leak pulse-pipe diaphragm allows compressed air to escape and lowers compressed-air pressure.

Too high a pressure (above ∿115 psig) creates a different problem. This occurs when enough pressure is not available to clean the entire length of a long bag. The pressure can be so high at the top of the bag that it blows holes or causes tears in the fabric. A diffuser insert manufactured by Sta-Clean is supposed to help equalize the pressure wave at the top and bottom of the bag and even to allow operation at a lower compressed-air pressure. Operating experience with this device seems to confirm that the tops of the bags are protected and more uniform cleaning of the bags occurs. This should extend bag life and lower energy requirements.

Bag blinding resulting from the presence of water and oil in the compressed-air supply can be solved in several ways. First, routine maintenance of the compressor can prevent worn compressor rings from passing oil into the compressed air systems. Second, a trap and/or air in-line dryer can be used to remove any water and oil. Third, the surge tank should be located such that compressed air entering the pulse pipe exits the tank from the top rather than the bottom. With this design, any water and oil that enter the surge tank will tend not to leave the tank except through a blowdown valve provided on the bottom of the tank. Figure 4-10 is an example of a top-mounted surge tank that can allow moisture to enter the pulse pipe. Lastly, if the compressor is beyond reasonable repair, a new one should be considered. Again, cost is important in the consideration of whether to repair or replace a compressor or install a dryer in the system. If the cost of one or two bag changes, however, is equivalent to the cost of a new compressor and the bags are lasting less than half of their normal expected life, the cost of replacement will be offset by the extended bag life. Another set of costs often overlooked are those associated with lost production caused by the

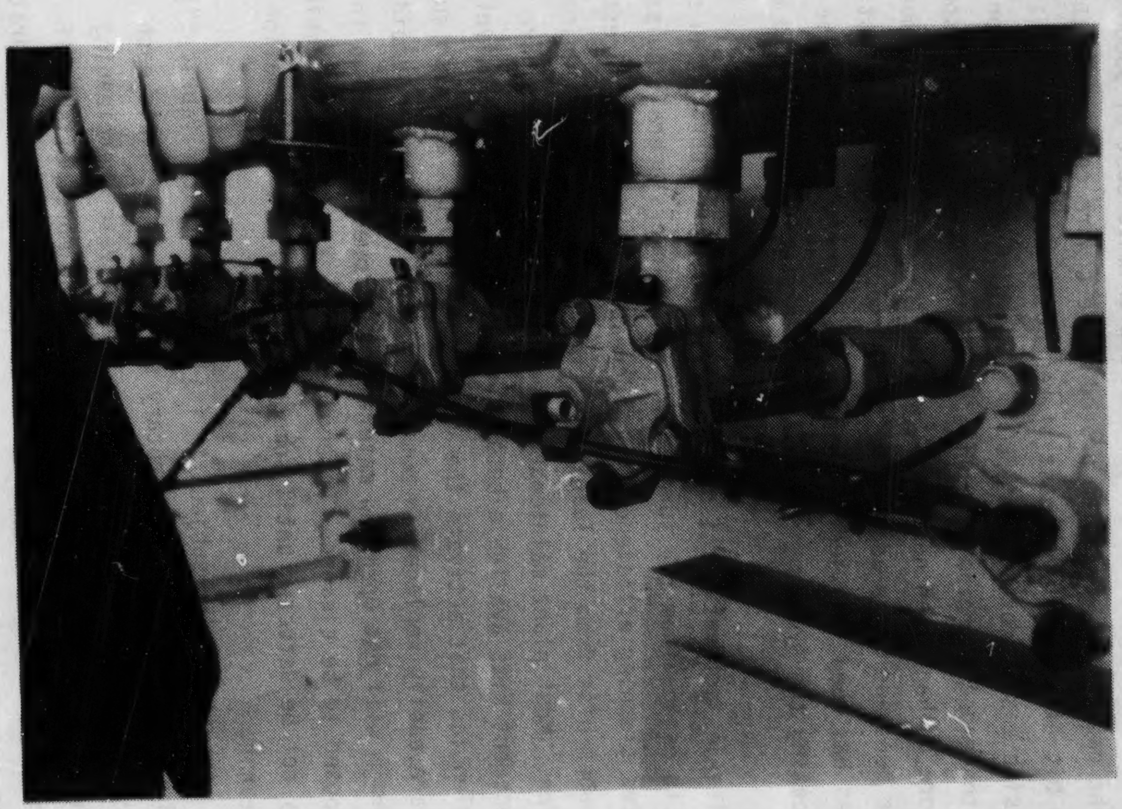

Figure 4-10. Diaphragm assembly for pulse-jet system with solenoid connection removed.
Top-mounted surge tank can allow oil and moisture
into blow pipe and subsequently onto the bags.
(Courtesy of PEI Associates, Inc.)

fabric filter being down and the cost of maintenance personnel to change the bags. The solution to the problem of bag blinding is to identify the cause of bag blinding and make the appropriate changes. Cost savings can be substantial. At one fabric filter installation, bags had to be changed once every 2 months because of bag blinding at an approximate cost of $5000 for bags alone. The cause of the problem proved to be a worn compressor that was losing quite a bit of oil, and the cost of replacing the compressor with one of equivalent size was approximately $5000. Even with a bag life of only 1 year (half of the expected normal bag life of 2 years), this company spent $25,000/year more on bags than necessary, and if the cost of lost production and maintenance personnel were added, the actual cost would be at least twice that amount. As has been stressed several times, identifying the cause rather than treating the symptom is usually the least-cost solution to any problem.

In the pulse-jet activation circuit, leakage of the diaphragm can cause compressed air to escape from the surge tank. This lowers overall pulse pressure, reduces cleaning efficiency, and increases fabric filter pressure drop. A continuous hiss from the leaking diaphragm is usually an indicator of this condition. Most plant maintenance personnel keep several spare diaphragm replacement kits available because repair is usually relatively simple. The solenoids that activate the various pulse-pipes are also subject to failure and are easily replaced in most designs. When these solenoids fail, the diaphragm will not open and material is allowed to build up in the row that is supposed to be cleaned. Depending on the fabric filter design, this problem may not be detected until someone checks for the activation of each row for cleaning.

The timing circuit is also subject to failure. The older fabric filters used mechanically driven and activated rotary switches to activate each solenoid. Newer designs use electronic timers to activate the cleaning system. These new systems tend to be more compact and more reliable if maintained properly. Both systems require clean, dry mountings to operate properly, and the presence of water and dust inside the timer enclosure can lead to failure of the timer circuits. The electronic timers also must be properly shock-mounted in a cool area. Electronic timers mounted on vibrating machinery have occasionally suffered from cracked circuit boards or loosened components as a result of the vibration. In addition, the solid-state components generally cannot withstand temperatures above 115° to 125°F for extended periods of time. Failure of the timing circuit will cause the bags to blind because they cannot be cleaned.

The last problem to be discussed with regard to pulse-jet systems is pulse-pipe alignment. When installed or replaced, the pulse pipes should be aligned over the row of bags so that the openings are centered over each bag and aimed down the centerline of the bags. The attachment technique on many pulse-pipe designs ensures this alignment. In some pipe designs, however, the pipes can be misaligned, as shown in Figure 4-11, and care should be taken to be sure these pipes are properly aligned. In addition, the end of the pipe that is away from the pulse supply must be bolted or clamped down. If this clamp is broken, pipe misalignment is likely and damage to the top of the bags can occur. Pipes that are loose usually create a rattle inside the clean-air plenum when the cleaning system is activated. Maintenance should be scheduled as soon as possible to correct this problem, as pulse pipes can break from the connectors and damage the bags.

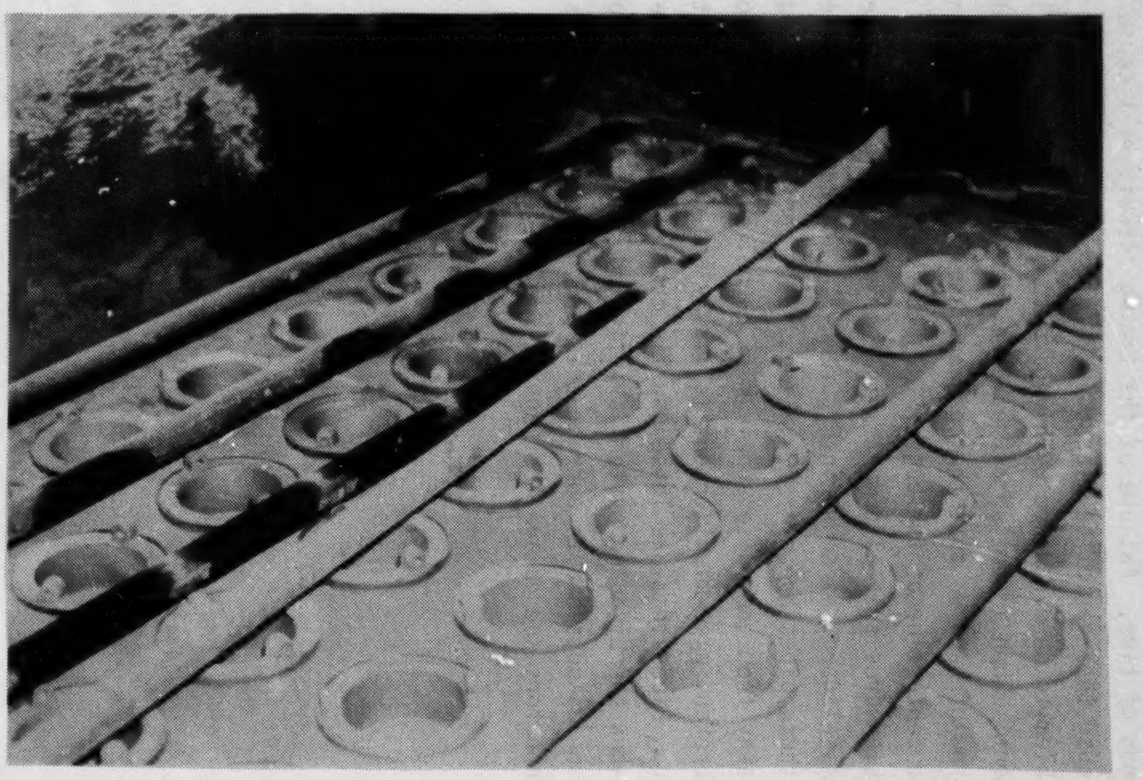

Figure 4-11. Misaligned blow pipe in pulse-jet fabric filter caused by a broken bolt at the end of the pipe. (This results in this row not being cleaned.) (Courtesy of PEI Associates, Inc.)

SECTION 5
O&M PRACTICES

The importance of proper design considerations, timely detection of malfunctions and bag failures, and good recordkeeping practices to fabric filter performance has been discussed. Also essential to satisfactory long-term performance of this control device are proper operating procedures and preventive maintenance practices. Although high-temperature fabric filters often receive the most attention, proper operating procedures are essential for both high- and low-temperature applications. This section discusses general operating procedures and preventive maintenance practices that can minimize unexpected malfunctions and improve the performance of the fabric filter.

5.1 OPERATING PROCEDURES

Proper operating procedures are important during startup, shutdown, normal operations, and emergency conditions. For any system, and particularly a new system, these procedures should include training of O&M personnel in design fundamentals, component operations, and the limitations and expected range of values of various operating parameters. Often this training is overlooked, thought to be too expensive, or left to on-the-job training. Whereas the cost of repairing the damage resulting from improper operation of some systems is not excessive, the cost can be substantial for other systems (e.g., large high-temperature units), particularly if failures recur as a result of continual operation in a manner that is incompatible with the system's design.

5.1.1 Startup Procedures

Improper startup can adversely affect many fabric filters. Most often these adverse effects will be reflected as an increase in pressure drop or a shortening of bag life, both of which increase the cost of operating the fabric filter.

For new fabric filters, a complete check of all the components is recommended prior to operation. Any necessary repairs or corrections are usually easier to make while the fabric filter is still clean. This component check should include operating the cleaning system, the dust-discharge system, and the isolation dampers and fans. It should also include passing clean ambient air through the system to confirm that all bags are properly installed. As a final check, fluorescent dye may be injected into the system to check for proper sealing of the tubesheet and bags. The use of fluorescent dye is usually reserved until some small amount of dust cake is built up on the bags so that the dust will not bleed through the bags.

New bags are prone to abrasion if subjected to high dust loadings and full-load gas flows. This is of particular concern during the initial startup, as new bags do not have the benefit of a dust buildup cake to protect the fibers from abrasion or to increase their resistance to gas flow. Introducing a full gas flow at high dust loadings can allow the particulate matter to impinge on the fabric at high velocity and result in abrasion that may shorten bag life. In addition, the dust may penetrate so deeply into the fabric that the cleaning system cannot remove it, and a "permanent" pressure drop results.

Two methods are available to prevent this problem with new bags. The first involves introducing a reduced gas volume into the fabric filter at a lower mass loading (if possible) to allow the dust cake to build gradually and gently. This prevents the particles from impacting the new bag fibers at full velocity. The second method involves the use of a precoat material to provide a protective filter cake before the process gas stream is introduced (see Figure 5-1). The precoat material may be the same dust that will be filtered during normal operation or some other dust that will provide suitable cake-release properties. Examples of precoat materials include fly ash and pulverized limestone. Although the use of a precoat material may be part of normal operation or routine startup procedures, it is also recommended when new bags are installed, when an abrasive dust situation exists, when the bag fabric has a low abrasion resistance, and when partial bag changeouts occur.

Dewpoint (both moisture and acid, if applicable) is a major concern during startup. The presence of moisture in the gas stream usually does not present a problem as long as the moisture is not allowed to condense within

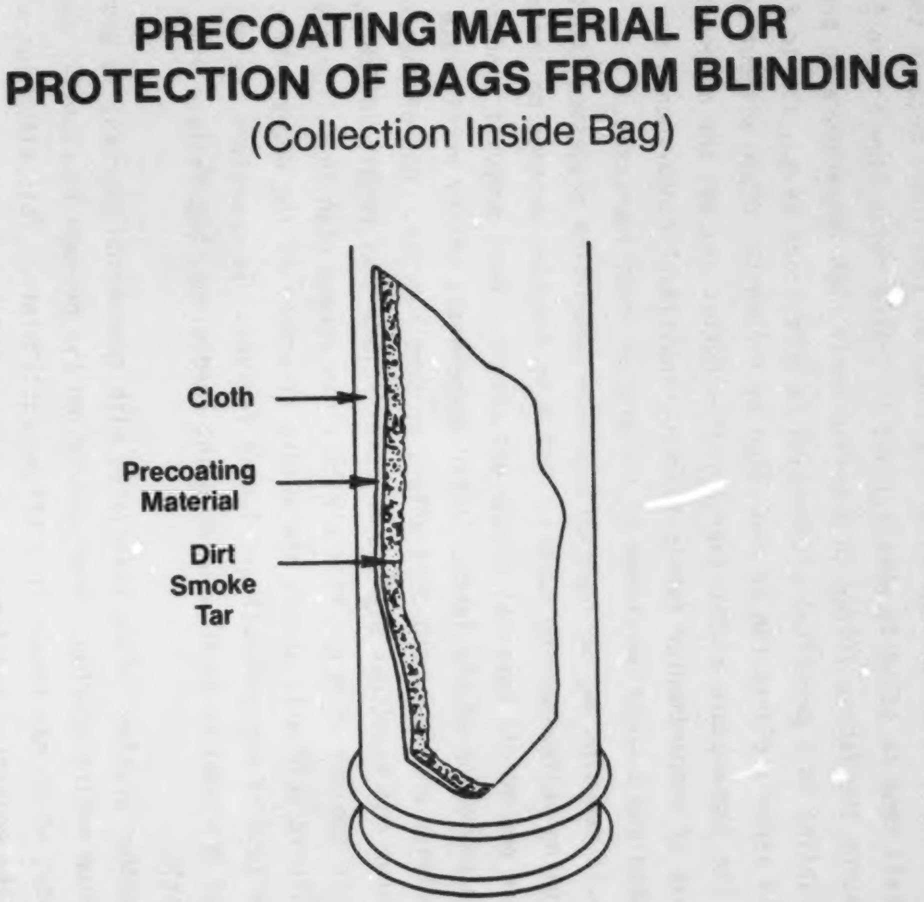

Figure 5-1. Precoating material for protection of bags from blinding.
(Courtesy of the Carborundum Co.)

the fabric filter. The introduction of warm moist gas into a cool or cold fabric filter can cause condensation on the bags or on the fabric filter shell. This moisture may cause bag blinding and a situation referred to "mudded" bags. Although some dusts can be heated, dried, and then removed from the bags, most will remain as a solid and perhaps impermeable dust cake that produces excessively high pressure drops. Special care must be taken with the use of some precoat materials (such as limestone) because these materials tend to solidify when allowed to become moist (see Figure 5-2). Preheating the fabric filter to a sufficiently high temperature to prevent condensation is a practical alternative in some cases (e.g., fabric filters used in asphalt plants can be preheated by firing the dryer without aggregate until the temperature at the fabric filter outlet exceeds the dewpoint). In the case of compartmented fabric filters, individual compartments can be preheated and brought on-stream as the process rate increases.

Acid dewpoint may be important on some combustion processes (most notably those using sulfur-bearing fuels). The acid dewpoint depends on the amount of moisture and acidic material in the gas stream. Acid dewpoint conditions can lead to corrosion of the fabric filter components, sticky particulate and cake-release problems, and acid attack on some fabrics. One of the most well-known but sometimes overlooked combinations that result in fabric acid attack is the use of Nomex fabric with a gas stream high in sulfuric acid. The sulfuric acid will attack the aramid structure of the Nomex fabric and cause a loss of bag strength and fabric failure. If operators are not made aware of the need to avoid acid dewpoint conditions, bag failure will occur frequently.

Another problem (often associated with combustion sources) is unstable combustion during startup. Poor combustion can produce substantial carbon carryover, which may result in a sticky particulate. This situation also can create the potential for fires in the fabric filter when a combustion source and an adequate supply of oxygen are available. Because fires on the bags and in the hoppers tend to destroy the fabric and necessitate bag replacement, hoppers should be emptied continually during startup. Coal-fired boilers in which oil is used during startup present problems in the areas of minimizing emissions and protecting the fabric filter. Bypassing the fabric filter until

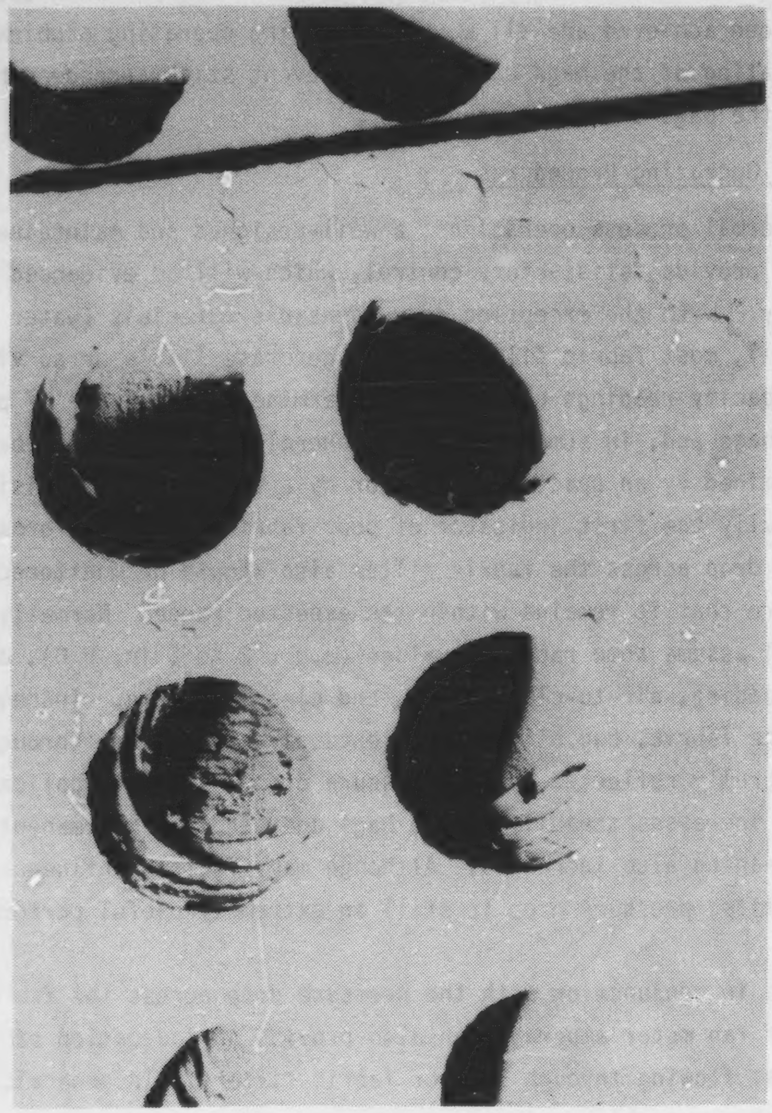

Figure 5-2. Limestone precoat hardened because of condensation (dewpoint) problems. (Bags became blinded and high pressure drops resulted.) (Courtesy of PEI Associates, Inc.)

stable coal operation is achieved, preheating the fabric filter, and bringing only the minimum number of compartments needed into service when stable combustion has been achieved are all ways of avoiding operating problems. Continuous precoating of the bags can help to prevent sticky (condensable) soot from fouling the bags during startup.

5.1.2 Normal Operating Procedures

During normal process operations, a well-designed and maintained fabric filter should provide satisfactory control, which will be evidenced by its outlet opacity. With the exception of condensable materials (water vapor, heavy organics), most fabric filters should generate little or no visible emissions. Opacity readings can help to determine the presence of pinholes and tears in bags and, in some cases, the general location of the bag failure. Whether determined by an opacity monitor or by a visual method, visible emissions are usually the first indicator of poor fabric filter performance.

Pressure drop across the fabric filter also should be monitored periodically to assure that it remains within the expected range. Normally, the equipment will assume some range of values (e.g., 2 to 6 in. H_2O), depending on the dust loading, air-to-cloth ratio, and cleaning cycle. Inadequate cleaning of the fabric, bag blinding, or excessive gas volume through the system is generally reflected in the pressure drop. In some applications, the pressure drop increases steadily as the bags age, and the "permanent" pressure drop after cleaning also increases. Although many factors influence pressure drop and bag life, pressure drop is still an extremely useful performance indicator.

When used in conjunction with the pressure drop across the fabric filter, measurement of fan motor amperage can also provide an indication of the quantity of gas flowing through smaller fabric filters. In general, an increase in current combined with an increase in pressure drop indicates an increase in gas volume, and a decrease in amperage reflects a decrease in gas volume. These changes, however, must be normalized for temperature (density) changes because temperature influences the energy required to move the gas through the system.

High-temperature operations should be equipped with continuous strip chart recorders and high temperature alarms (see Figure 5-3). The high-temperature alarms should provide some margin for corrective action, i.e., set points of 50° to 75°F below the high temperature limit of the fabric. The temperature alarm/recorder also may be connected to some automatic damper system to control the temperature or to bypass the fabric filter. Although some differential between the maximum temperature and the alarm activation must be provided, the temperature set point should not be so low that the alarm is continually activated. The temperature indicator will also monitor against excessively low temperatures and dewpoint problems.

5.1.3 Shutdown Procedures

Dewpoint conditions and dust removal from the fabric filter are the primary concerns during shutdown. Failure to follow recommended shutdown procedures also can result in early bag failure. Avoiding dewpoint conditions through system purging is of top priority; bag cleaning and hopper emptying are lower-priority items.

When processes operate on a daily cycle, the last operation of the day should be to purge moisture and acidic materials from the fabric filter without passing through the dewpoint. For example, an asphalt plant might allow the dryer to operate for several minutes with the burner on after the aggregate has been removed from the drum to remove moisture from the fabric filter. Ambient air could then be drawn through the system to purge the remaining combustion products from the fabric filter. Even well-insulated fabric filters usually have trouble maintaining temperatures above dewpoint for more than several hours; therefore, it is advisable to purge these systems when long idle periods are expected.

Upon shutdown, at least one or two complete cleaning cycles should be allowed in compartmented fabric filters, and 5 to 20 minutes of cleaning in pulse-jet systems. Removing the dust from the bags in this fashion will help prevent blinding of the bags. Continuing to operate the hopper discharge system while the cleaning system is in operation will minimize the chance of hopper pluggage.

When emergency shutdowns of the fabric filter are necessary because of high temperatures, spark detection, or other process upsets, the fabric filter

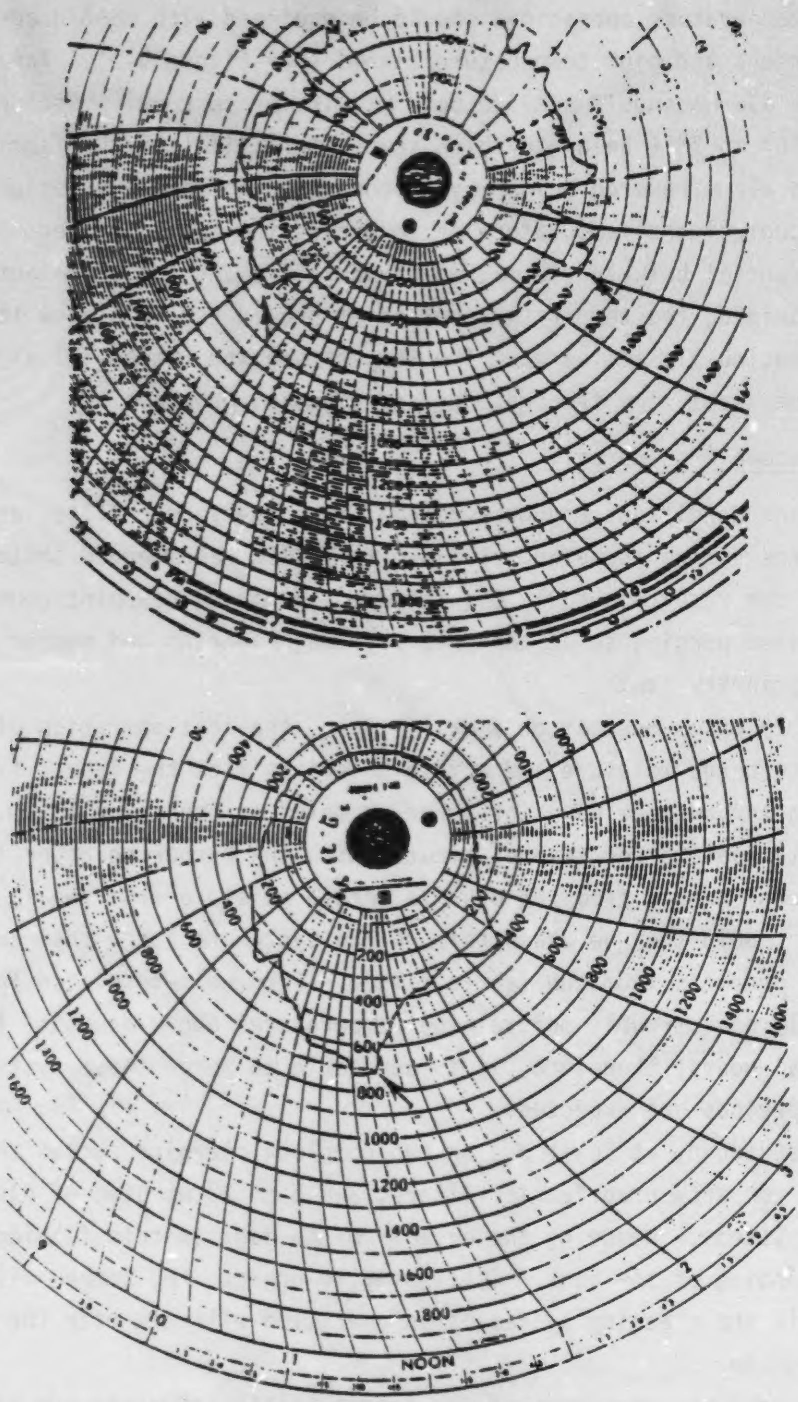

Figure 5-3. Examples of strip chart output on a fabric filter with high temperature excursions as indicated by arrows. (Courtesy of PEI Associates, Inc.)

is usually bypassed to prevent failures and to protect the system from damage. For such major problems as fires in the hoppers or on the bags, however, it is probably better to let them burn out rather than to cut off the gas flow immediately. Allowing the ignition source into a fabric filter without any gas flow may cause an explosion. Also, adding water to a burning fabric filter or to a hopper fire is not always advisable. In some situations, the addition of water under reduced (oxygen-starved) atmospheric conditions will hydrolyze the water and form hydrogen, which can create the potential for an explosion within the fabric filter. The fabric filter manufacturer and insurance carrier should be contacted whenever a known potential for fires/explosions exists.

Other process failures may necessitate only temporary bypassing of the fabric filter, and the operation can be restored in a matter of minutes. In these cases, the fabric filter generally does not have to be shut down completely and purged. If the upset cannot be corrected within a reasonable amount of time, however, shutdown and the subsequent startup of the fabric filter may then be necessary to prevent dewpoint problems.

It is important to note that bypassing the fabric filter during startup, soot blowing, or an emergency may not be acceptable to the applicable regulatory agency. Such occurrences should be investigated and accounted for during the design stages of development.

5.2 PREVENTIVE MAINTENANCE PRACTICES

The wide range of fabric filter applications makes specification of preventive maintenance practices a difficult task. Recordkeeping is the heart of any preventive maintenance program because it permits determination of patterns that point to the possibility of major problems on the horizon. For a fabric filter, recordkeeping centers on bag life and bag replacement, but other items also must be considered.

5.2.1 Overall Maintenance Inspection Checklist

The following is a general checklist of items that should be inspected regularly as part of a comprehensive O&M inspection program.[1-6]

- Inspect filter media for blinding, leakage, wear, slack, bag tension, and loose bag clamps, or discoloration.

- Inspect the overall collector and compartment housings, hooding, and connecting ductwork for leakage, corrosion, or dust accumulation.
- Inspect all solenoid-operated pneumatic damper actuators, airlocks, and valves for proper seating, dust accumulation, leakage, synchronization, and operation.
- Inspect hopper discharge for possible bridging of dust.
- Measure the bag pressure drop. Compare frequency of cleaning with that recommended by the manufacturer.
- Inspect fan bolts (for tightness), bearings (for vibration), and temperature. Inspect for erosion or dust buildup in the housing and on the wheel. Check alignment of fan impeller with V-belt drive or coupling and driver. Check sheave for signs of V-belt wear.
- Inspect all bearings on fans, motors, dampers, etc., for lubrication and free rotation.
- Inspect foundation bolts on collector, motor, fan, etc., for tightness. Also inspect bolts on collector housing and structural members.
- Inspect access doors(s) for leaks due to faulty gaskets or warping of door(s) and/or frame(s).

Although the inspection frequency for an individual fabric filter system will depend on the type of system and the vendor's recommendations, certain major components should be inspected on a routine basis, and any needed maintenance should be performed. Table 5-1 summarizes the inspection and maintenance schedule for the major components of a fabric filter system.

5.2.2 Daily Inspection/Maintenance

At least twice per shift (and perhaps as often as every 2 hours), opacity and pressure drop should be checked. Sudden changes in these values along with those of temperature and gas volume, may indicate a problem. For example, the failure or partial failure of the cleaning system generally will cause a relatively rapid increase in pressure drop in most systems. Timely identification, location, and correction of this problem can minimize operating problems and long-term effects on bag life. Although identification and subsequent correction of relatively minor problems have little effect on fabric life, some minor problems tend to turn into major failures. Thus, the

TABLE 5-1. TYPICAL MAINTENANCE INSPECTION SCHEDULE FOR A FABRIC FILTER SYSTEM[1-6]

Inspection frequency	Component	Procedure
Daily	Stack and opacity monitor	Check exhaust for visible dust.
	Manometer	Check and record fabric pressure loss and fan static pressure. Watch for trends.
	Compressed air system	Check for air leakage (low pressure). Check valves.
	Collector	Observe all indicators on control panel and listen to system for properly operating subsystems.
	Damper valves	Check all isolation, bypass, and cleaning damper valves for synchronization and proper operation.
	Rotating equipment and drives	Check for signs of jamming, leakage, broken parts, wear, etc.
	Dust removal system	Check to ensure that dust is being removed from the system.
Weekly	Filter bags	Check for tears, holes, abrasion, proper fastening, bag tension, dust accumulation on surface or in creases and folds.
	Cleaning system	Check cleaning sequence and cycle times for proper valve and timer operation. Check compressed air lines including oilers and filters. Inspect shaker mechanisms for proper operation.
	Hoppers	Check for bridging or plugging. Inspect screw conveyor for proper operation and lubrication.

(continued)

TABLE 5-1 (continued)

Inspection frequency	Component	Procedure
Monthly	Shaker mechanism	Inspect for loose bolts.
	Fan(s)	Check for corrosion and material buildup and check V-belt drives and chains for tension and wear.
	Monitor(s)	Check accuracy of all indicating equipment.
Quarterly	Inlet plenum	Check baffle plate for wear; if appreciable wear is evident, replace. Check for dust deposits.
	Access doors	Check all gaskets.
	Shaker mechanism	Tube type (tube hooks suspended from a tubular assembly): Inspect nylon bushings in shaker bars and clevis (hanger) assembly for wear. Channel shakers (tube hooks suspended from a channel bar assembly): Inspect drill bushings in tie bars, shaker bars, and connecting rods for wear.
Semiannually	Motors, fans, etc.	Lubricate all electric motors, speed reducers, exhaust and reverse-air fans, and similar equipment.
Annually	Collector	Check all bolts and welds. Inspect entire collector thoroughly, clean, and touch up paint where necessary.

operation of a fabric filter should be tracked on a daily basis to assure early detection of any problems. The ability to perform on-line maintenance depends on the design of the control equipment.

Routine checks of the fabric filter include pressure drop (and patterns if a ΔP indicator and recorder are used), opacity patterns, dust discharge operation, and external checks of the cleaning system operation. Other factors that can be checked include temperature (range) and fan motor current. If a check of these factors reveals a sudden change, maintenance should be scheduled as soon as possible.

5.2.3 Weekly Maintenance/Inspection

The extent of the weekly maintenance program depends greatly on access and design of the fabric filter. Where possible, quick visual inspections should be conducted; however, not all systems or processes are amenable to this type of review. A weekly lubrication schedule should be established for most moving parts. Manometer lines should be blown clear, and temperature monitors should be checked for proper operation.

Shaker-Type Fabric Filters--

The operation of isolation dampers should be checked along with the operation of the shaker system. The intensity of shaking should be relatively uniform throughout the compartment. Bag tension should be checked, and any fallen bags should be noted and repaired. The presence of any dust deposits on the clean side of the tubesheet also should be noted, as well as any holes or leaks in the bags.

Reverse-Air Fabric Filters--

The operation and sealing of the isolation and reverse-air dampers should be checked. Each compartment should be checked for proper bag tension during reverse-air operation, and any fallen bags should be noted and repaired. The presence of dust deposits on the clean side of the tubesheets should be noted to determine if there are any holes and leaks in the bags and if the seals are tight. Tubesheets should be cleaned periodically to keep deposits from building up around the bags.

Pulse-Jet Fabric Filters--

On the dirty side of the tubesheet, bags should be checked for relatively thin and uniform exterior desposits. Bags also should be checked for bag-to-bag contact (points of potential bag wear). On the clean side of the tubesheet, each row of bags should be examined for leakage or holes. Deposits on the underside of the blowpipes and on the tubesheet may indicate a bag failure. The cleaning system should be activated (the inspector should use hearing protection), and each row of bags should fire with a resounding "thud." The blowpipes should remain secured, and there should be no evidence of oil or water in the compressed air supply. The surge tank or oil/water separator blowdown valve should be opened to drain any accumulated water. Misaligned blowpipes should be adjusted to prevent damage to the upper portion of the bag. The compressed air reservoir should be maintained at about 90 to 120 psi.

5.2.4 Monthly-Quarterly Maintenance and Inspection

Beyond weekly inspections, the requirements become very site-specific. Clear-cut schedules cannot be established for such items as bag replacement and general maintenance of the fabric filter. Some items, however, may warrant quarterly or monthly inspections, depending on site-specific factors. Items to be checked include door gaskets and airlock integrity to prevent excessive inleakage (both air and water) into the enclosure. Any defective seals should be replaced. Baffles or blast plates should be checked for wear and replaced as necessary, as abrasion can destroy the baffles. Some facilities prefer to use fluorescent dye to check the integrity of the bags and bag seals (see Figure 5-4). Any defective bags should be replaced, and leaking seals should be corrected.

Bag failures tend to occur shortly after installation and near the end of a bag's useful life. A record of bag failures and replacements is invaluable for identifying recurrent problems and indicating when the end of bag life has been reached. Initial bag failures usually occur because of installation errors or bag manufacturing defects. When new bags are installed, a period

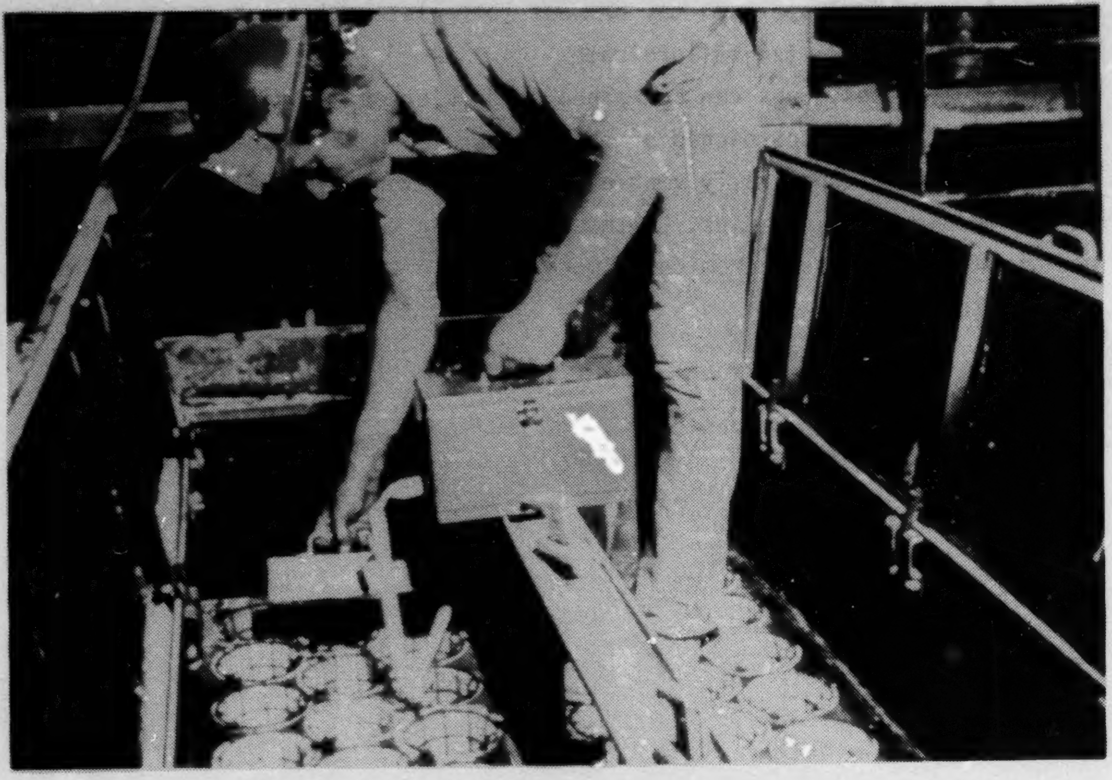

Figure 5-4. Use of an ultraviolet light to check for leaks of fluorescent dye that has been injected into the fabric filter. (Courtesy of BHA Baghouse Accessories Co., Division of Standard Havens, Inc.)

with few or no bag failures is normally expected unless serious design or operation problems exist. As the bags near the end of their useful life, however, the number of bag failures may increase dramatically. When weighed against factors such as downtime for rebagging, the cost of new bags, and the risk of limited production as the result of keeping the old bags in service, the most economical approach may be just to replace all the bags at one time to eliminate or minimize failure rate.

In some cases, bags can be washed or drycleaned and reused, e.g., when dewpoint limits are approached or the bags are blinded in some manner. This is generally an economically viable option when more than half a bag's "normal" life expectancy remains. Although cleaning may shorten bag life somewhat, sometimes it is economically more feasible to clean the bags than to replace them.

REFERENCES FOR SECTION 5

1. Zurn Industries. Start-Up Procedure. Operation and Proposed Maintenance Instructions. Air Systems Division, Birmingham, Alabama. 1980.

2. Flex-Kleen/Research Cottrell. Installation, Operating and Maintenance Manual. Bulletin 399. Chicago, Illinois. 1980.

3. Ecolaire Environmental Co. Operation and Maintenance Literature. Pleasant Hill, California. 1980.

4. W. W. Sly Manufacturing Co. Instruction Book, No. 693. Cleveland, Ohio. 1980.

5. Mikro-Pul Corp. Owner's Manual Micro-Pulsaire Dry Dust Collector, SD379a. Section VII C - Troubleshooting. Summit, New Jersey. 1980.

6. Mikro-Pul Corp. Owner's Manual, Micro-Pulsaire Dry Dust Collector, SD578, Section VII C - Troubleshooting. Summit, New Jersey. 1980.

SECTION 6
INSPECTION METHODS AND PROCEDURES

This section presents step-by-step procedures and techniques for detailed external and internal inspections of fabric filters.

Fabric filter inspections are performed for the following purposes: as part of system startup, for troubleshooting, to determine compliance with regulations, and as part of an overall operation and maintenance (O&M) program.[1,2,3]

The purpose of any fabric filter inspection is to determine the current operating status and to detect deviations that may reduce performance or cause failure at some future date. For this reason, inspection programs must be designed to derive maximum benefit from the information gathered during the inspection.

A properly designed inspection program can be used for three purposes: recordkeeping, preventive maintenance, and diagnostic analysis. Depending on its purpose, the inspection may be conducted by operators, maintenance staff, regulatory agency inspectors, or outside consultants (vendor representatives).

6.1 PRESTARTUP INSPECTIONS

Because most fabric filters use a centrifugal fan, the compatibility of the fan and the fabric filter is very important.[4] On startup, the fan resistance will be considerably lower than the operating design level because of the new bags, and the gas delivery rate may exceed the design value. This can have two undesirable effects: 1) the fan power level may rise to a point where the motor will overload and/or the higher-than-design volume flow may cause excess penetration; and 2) this higher volume flow may damage the filter medium.[3,5,6] The overall system resistance often is so high that variations in the pressure between new and used bags are too small to have a significant effect on fan capacity.[1,7,8] On systems in which the design pressure loss across the fabric represents a large fraction of the total pressure loss, the potential overload situation can be minimized by damper adjustment, selection of a fan with nonoverloading characteristics, or the use of adjustable inlet vanes. All dampers and/or inlet vanes should be partially closed during startup to reduce power consumption. After the operating fan speed has been attained and the overall system temperature approaches the operating level, the damper should be opened carefully to avoid motor overload.[9]

Before the initiation of normal operation, the inspector should check several items as indicated:[2,3,5,6,9,10]

- Inspect all bag compartments and ductwork to see that joints are tight. The general location of air leaks in either positive or negative pressure baghouses can often be detected audibly, and exact locations can be established by applying a soap solution to the suspected leak area.
- Inspect all bolts to ensure that they are tight. Inspect and properly lubricate (as applicable) all threaded elements on clamps and door latches for corrosion protection and easy access.
- Inspect bags to ensure that they are secured to the floor thimbles or cages. If bags are furnished with ground wires to guard against sparking (and dust explosions), they should be securely connected to the tube sheet, which must be well-grounded.
- Inspect all system controls to verify installation and operation in accordance with manufacturer's recommendations.[9,11-16]
- Inspect fan to ensure that it rotates in the proper direction. A visual inspection is recommended to identify this occasional cause of high pressure loss, reduced amperage, and diminished air handling capacity.
- Inspect the fan and motor system for vibration, noise, and, in particular, overheated bearings.

6.2 STARTUP INSPECTION PROCEDURES

The startup and shutdown procedures depend on the type of fabric filter (shaker, reverse-air, or pulse-jet) and the process or emissions being controlled. Two examples are used to illustrate the startup inspection procedures. The first is a pulse-jet fabric filter and the second is a reverse-air system, both used to control a combustion process.[12,14]

6.2.1 Pulse-Jet System

The following procedures should be followed during the startup of a pulse-jet system:[12]

- Check to see that the inlet damper is opened fully after the bag pressure differential has increased to 3 to 4 in. water.
- Do not activate the timer controlling the compressed air pulses until the differential pressure has reached 4 to 5 in. water unless operating conditions require a lower pressure drop.
- During normal startup with seasoned or conditioned bags, apply power to all auxiliary equipment (except fan), energize the timer, and start the compressed air system.
- Turn on fan motor with the system damper nearly closed to prevent motor overload during the starting power surge.
- Maintain the pressure loss across the fabric within its preset range by adjusting the pulse jet cleaning cycle. More frequent and higher pressure pulses will reduce the bag pressure loss, whereas the opposite actions will increase bag pressure loss should the need arise to reduce dust penetration.
- When the system is to be shut down, first turn off the fan and then close the inlet and exhaust dampers. After waiting 15 to 30 minutes, shut off the compressed air and timing circuit, along with any auxiliary equipment.
- Be sure the hopper(s) are emptied of material before turning off the airlock and/or screw conveyor. This step will reduce the chance of dust hangup and plugging due to compaction and sticking of the dust in condensing atmospheres.

6.2.2 Reverse-Air System

The objective during startup of a reverse-air fabric filter is to prevent flue gas from entering the fabric filter until the fabric filter is completely preheated and the bags are precoated. By minimizing penetration of fine particles into the fabric structure, these precautionary steps reduce the chance of premature filter plugging or blinding. Prior to actual startup, the system should be checked to verify that all control elements, dampers, and fans are functioning properly.[14] The following are prestartup procedures:

- Preheat compartments by using hopper heaters, if available.
- Preheat inlet duct with flue gas from gas- or oil-fired boiler, if available, and if the damper arrangements are such that this can be accomplished.
- Preheat fabric filter with hot flue gas from gas- or oil-fired boiler, if available.
- Precoat bag surfaces.
- Visually inspect filtration surface to ensure that bags are coated.

6.3 ROUTINE PREVENTIVE MAINTENANCE INSPECTIONS

This section presents suggested procedures for performing routine preventive maintenance inspections of typical pulse-jet, reverse-air, and shaker type fabric filters.

6.3.1 Pulse-Jet Fabric Filters

Evaluation of Plume Characteristics--

An average opacity should be predetermined. Most pulse-jet collectors operate with less than 5 percent opacity, so values approaching 5 percent may suggest operating problems. If puffs are observed, the timing should be noted so that it is possible to identify the row being cleaned just before the puff.

Filtration System--

The pressure drop across the collector should be noted. If there is a gauge, proper operation of the gauge should first be confirmed by observing meter response during the pulsing cycle. If there is some question about the condition of the gauge or its connecting lines, one line at a time should be disconnected to identify any plugged or crimped lines (disconnecting lines may not be possible if there is a differential pressure transducer connected to the gauge lines).

If a properly operating gauge is not available, the static pressure drop should be measured with portable instruments. These measurements should be made at isolated ports installed specifically for the use of portable instrumentation. It is important to make the measurements on the inlet and the outlet one at a time so that plugged tap holes and lines can be identified.

The operation of the cleaning system should be checked by noting the air reservoir pressure. The ends of the reservoir and the connections to each of the diaphragm valves should be checked for air leakage. Because these valves are normally activated on a frequent basis, it is usually possible to observe a complete cleaning cycle. Each valve should generate a crisp thud when activated. Valves that fail to activate or that produce a weak sound when activated are usually not working properly (see Figure 6-1). If too many of these valves are out-of-service, the air-to-cloth ratios are probably high, which can cause excessive emissions through the baghouse or inadequate pollutant capture. Even if all diaphragm valves are working properly, reduced cleaning effectiveness can result from the low compressed-air pressures.

If the compressed-air pressures are too high, especially for units designed with a high air-to-cloth ratio, the intense cleaning action could result in some seepage of dust through the bag fabric immediately after cleaning, when the bag is pushed into the support cage. This will cause a momentary puff of 5 to 10 percent opacity.

Holes and tears can lead to puffs of 5 to 30 percent opacity during the cleaning cycle. During the pulse, the material bridged over these areas is removed and the particulate matter is allowed to leak through (see Figure 6-2). As soon as the pulse dissipates, material tends to bridge over the holes again, and the area eventually heals. As the holes and tears increase in size, the duration of the puff also increases. Continuous emissions result when the holes and tears become too large to bridge over.

The discharge of solids from the filter hopper should be observed if this can be done safely and conveniently. Solids are usually discharged on a fairly continuous basis (following each pulsing of a row).

Compressed-Air System--

The compressed-air system should be inspected to determine whether it contains any water or rust deposits that could cause the system to malfunction. One quick method of checking whether the system has water or rust deposits is to carefully open the valve on the blowdown system and observe whether any water or other material is being expelled through the valve. Also, if the system has oil traps, the traps can be visually inspected to determine if any water or other material is retained in the trap.

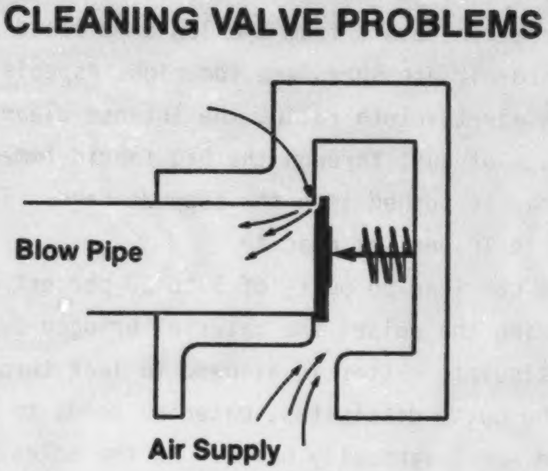

Figure 6-1. Cleaning valve problems.
[Illustration reproduced from "The Maintenance of Exhaust Systems in the Hot Mix Plant (IS-52A)" published by the National Asphalt Pavement Association.]

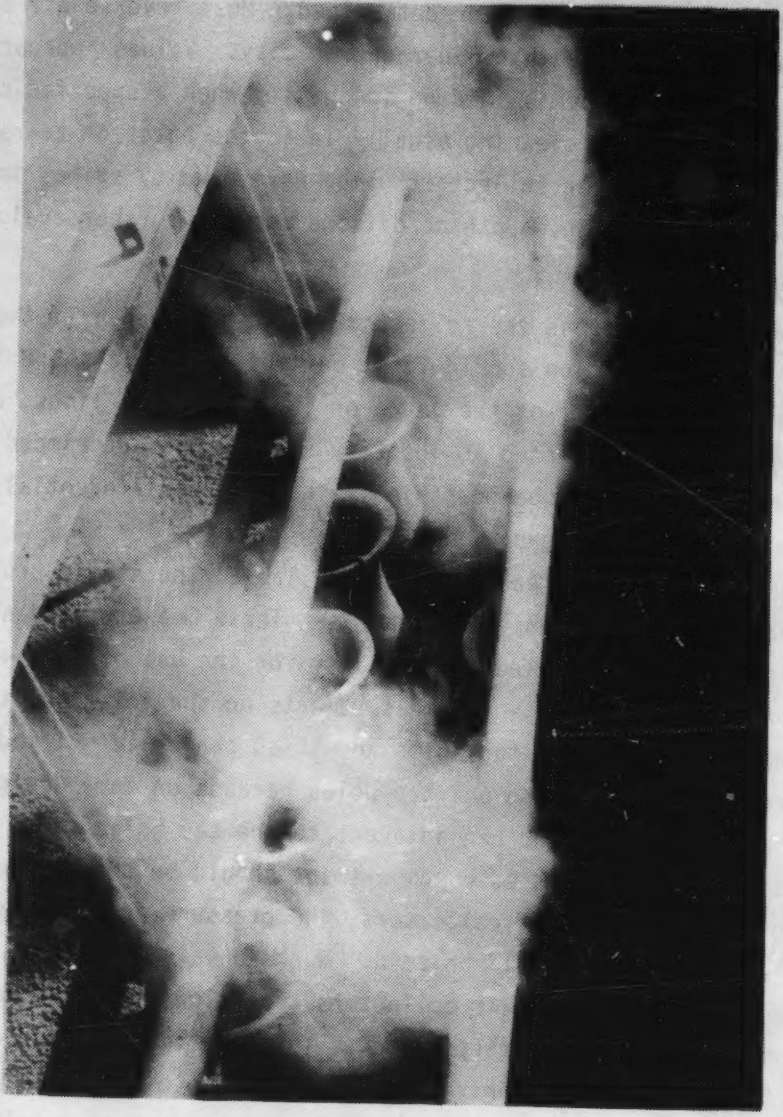

Figure 6-2. Pinhole leaks in bags can be determined by watching for emissions immediately after the cleaning pulse is fired, as shown for the right-hand row of bags in this photo.
(Courtesy of PEI Associates, Inc.)

6.3.2 Reverse-Air and Shaker Fabric Filters

Evaluation of Plume Characteristics--

An average opacity should be predetermined. Most reverse air and shaker collectors operate with less than 5 percent opacity. Values approaching this may suggest operating problems. A drop in opacity when a specific compartment has been isolated for cleaning usually indicates holes or tears in bags in that compartment. Shaker collectors often have opacity spikes immediately following the cleaning cycle. Both conditions warrant further evaluation.

Filtration System--

The pressure drop across the collector should be noted. If there is a gauge, its proper operation should first be confirmed. If there is some question about the condition of the gauge or its connecting lines, one line at a time should be disconnected to identify any plugged or crimped lines (disconnecting lines may not be possible if there is a differential pressure transducer connected to the gauge lines).

If a properly operating gauge is not available, the static pressure drop should be measured with portable instruments. These measurements should be made at isolated ports installed specifically for the use of portable instruments. It is important to make the measurements on the inlet and the outlet one at a time so that plugged tap holes and lines can be identified. Care must be exercised while rodding out tap holes because on some designs it is possible to poke a hole in the bag adjacent to the tap hole.

The pressure drop across each compartment should be determined during the cleaning cycle. In shaker collectors, the pressure drop during the cleaning of a compartment should be zero. Nonzero values indicate damper leakage problems. In reverse-air collectors, backflow will cause a measurable pressure drop with a polarity opposite that of the filtering cycle. If no gauge is available and the unit operates at an elevated gas temperature, the gas temperature should be measured. This can be done at a point on the inlet duct to the collector or at one of the tap holes (if direct access to the interior of the collector is possible).

The rate of solids discharge should be checked, if this can be done safely and conveniently. Solids are usually discharged only at the beginning of the cleaning cycling in each compartment.

Air leakage through access hatches, solids discharge valves, hopper flanges, and fan isolation sleeves should be checked by listening for the sound of inrushing air.

6.4 DIAGNOSTIC INSPECTIONS

This section presents a suggested procedure for performing diagnostic inspections of typical pulse-jet, reverse-air, and shaker type fabric filters when certain problems arise.[20]

6.4.1 Pulse-Jet Systems

High Opacity (continuous or puffs)--

On top-load type designs, the clean side of several compartments should be checked if these can be safely isolated and if no pollutant capture problems will result at the source origin. Even slight dust deposits can be a sign of major problems (most of the dust in the clean-side plenum is carried out because of the relatively high gas velocities). Dust near one or more bag outlets may suggest inadequate sealing on the tube sheet. Holes and tears may disperse dust throughout the top side of the tube sheet and make it difficult to identify the bag with the hole. Fluorescent dye may be used later to identify the problem.

High Pressure Drop, High Opacity, or Process Fugitive Emissions--

For a top-access system, the possibility of fabric blinding can be checked from the top access hatch. Oil and water in the compressed air line are sometimes partially responsible for the blinding that takes part of the fabric area out of service.

For conventional pulse-jet collectors, the possibility for blinding can only be checked at the dirty-side access hatch. Figure 6-3 shows an example of easily removable dust. A crusty cake is sometimes evidence of excessive moisture or sticky deposits on the bags.

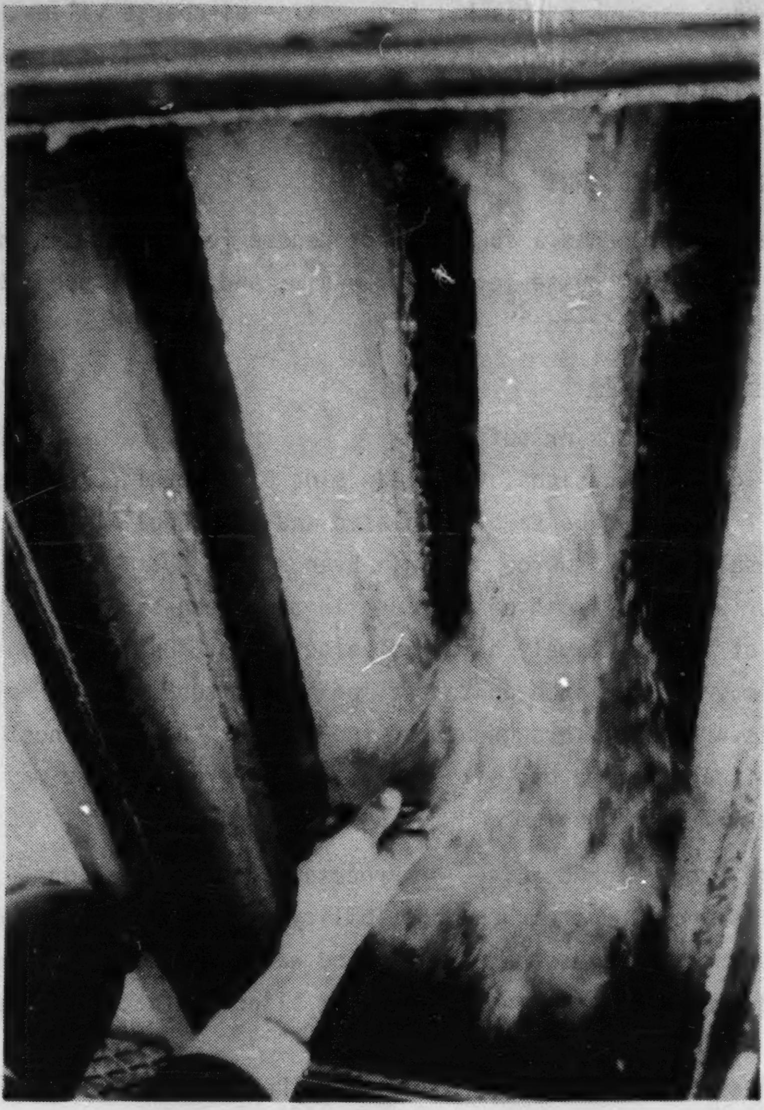

Figure 6-3. Knocking dust off bags to see how easily removable it is. (In this case, the material was dry and easily removable, but the cleaning mechanism was not working.)
(Courtesy of PEI Associates, Inc.)

Continuously High Opacity, Frequent Bag Failures (primarily at bottom)--

Both types of pulse-jet collectors can experience possible premature bag failure at the bottom if the support cages are slightly warped and the bags rub at the bottom. This can be checked from a dirty-side access hatch, or in some cases from below as shown in Figure 6-4. Note: Only the operator (using extreme caution) should open the hatches at the tops of hopper areas. Hot solids can flow rapidly out of these hatches.

The bag failure charts for the fabric filter should be examined. If a distinct spatial pattern is apparent, the damage may be due to abrasion (inlet gas blasting, inlet swirling, or rubbing against internal supports). The date of the bag removal and the elevation of the apparent damage (T-top, M-middle, B-bottom) enable identification of many common modes of failure. By using such charts, operators have been able to minimize both excess emission incidents and bag replacement cost. A rapid increase in the rate of failure often suggests significant deterioration of fabric strength due to chemical attack or high temperature excursions.

When bags are removed from service, a simple rip test should be performed. If it is possible to rip the cloth by inserting a screw driver and pulling, the bag damage probably was the result of chemical attack, high temperature excursions, moisture attack, or routine fabric exhaustion. Most fabrics damaged by abrasion-related problems cannot be ripped, even near the site of the damage.

High Opacity and Distinct Pattern to Bag Holes and Tears--

Bag and cage assemblies should be carefully inspected on removal. Often the point of bag failure is next to a sharp point on the support cage. Premature failure may also be caused by cages that do not provide enough support for the fabric.

If all the bags have failed at the top, the compressed-air nozzles may be misaligned (see Figure 6-5). This can cause the pulse to be directed at a narrow area at the top of the bag.

6.4.2 Reverse-Air and Shaker Type Fabric Filters

Suspected Air Leakage, Low Gas Temperature, or Low Pressure Drop--

The O_2 and CO_2 levels at the inlet and outlet of combustion source fabric filters should be checked. The measurement point on the inlet must be

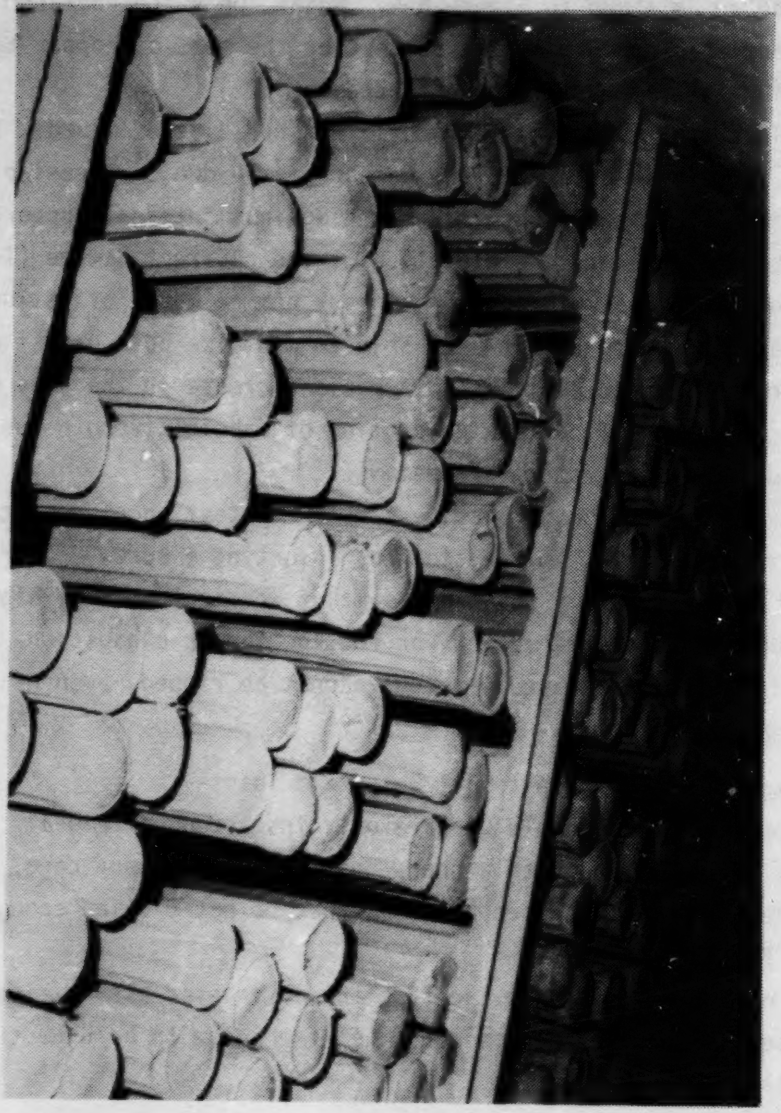

Figure 6-4. Bag-to-bag contact in a pulse-jet fabric filter resulting from poor alignment of cages during installation. (Courtesy of PEI Associates, Inc.)

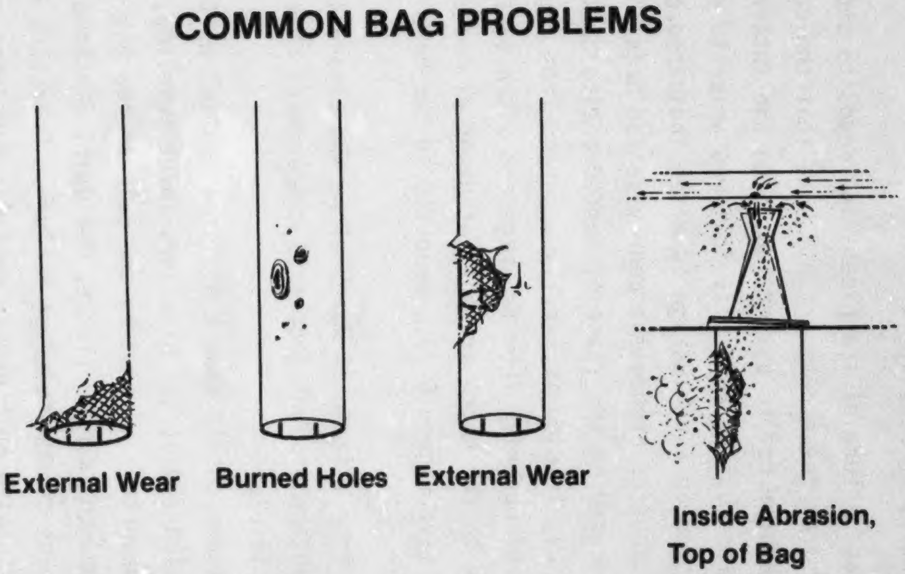

Figure 6-5. Common bag problems with pulse-jet fabric filters, including abrasion at the top of the bags caused by misalignment of compressed air nozzles. (Courtesy of National Asphalt Pavement Association)

between the solids discharge valve and the tube sheet, so that potential inleakage at this point can also be taken into account. There should not be more than a 1 percent rise in the O_2 levels going from the inlet to the outlet (e.g., 6% O_2 in and 7% O_2 out).

Continuously High Opacity (during most of operating period) or Pressure Drop Much Greater or Lower than Baseline--

The presence and nature of the clean-side deposits should be checked by viewing conditions from the access hatch. Note that the compartment must be isolated by the operator before attempting to do the internal inspection. All safety procedures must be carefully followed prior to entry.

The presence of snap ring leakage is often indicated by enlarged craters in the clean-side deposits around the poorly sealed bags. Holes and tears can sometimes be located by the shape of dust deposits next to the holes (see Figure 6-6). Poor bag tension is readily apparent from the access hatch. Improper discharge of material from the bags can often be confirmed by noting that the bags close to the hatch are full of material one or more diameters up from the bottom (see Figure 6-7). Deposits on the bags should also be noted.

Anything more than a trace of material on the clean-side tube sheet is indicative of probable emissions from this compartment that are substantially above the baseline levels.

If the bag failure charts show a distinct spatial pattern, the damage may be due to abrasion (inlet gas blasting, inlet swirling, and/or rubbing against internal supports). Including the date of the bag removal and the elevation of the apparent damage (T-top, M-middle, B-bottom) makes it possible to identify many common modes of failure. Operators using such charts have been able to minimize both excess emission incidents and bag replacement cost. A rapid increase in the rate of failure often suggests significant deterioration of fabric strength. A simple rip test should be performed on a bag recently removed from service. If it is possible to rip the cloth by inserting a screw driver and pulling, the bag damage was probably the result of chemical attack, high temperature excursions, moisture attack, or routine fabric exhaustion. Most fabrics damaged by abrasion-related problems cannot be ripped, even near the site of the damage.

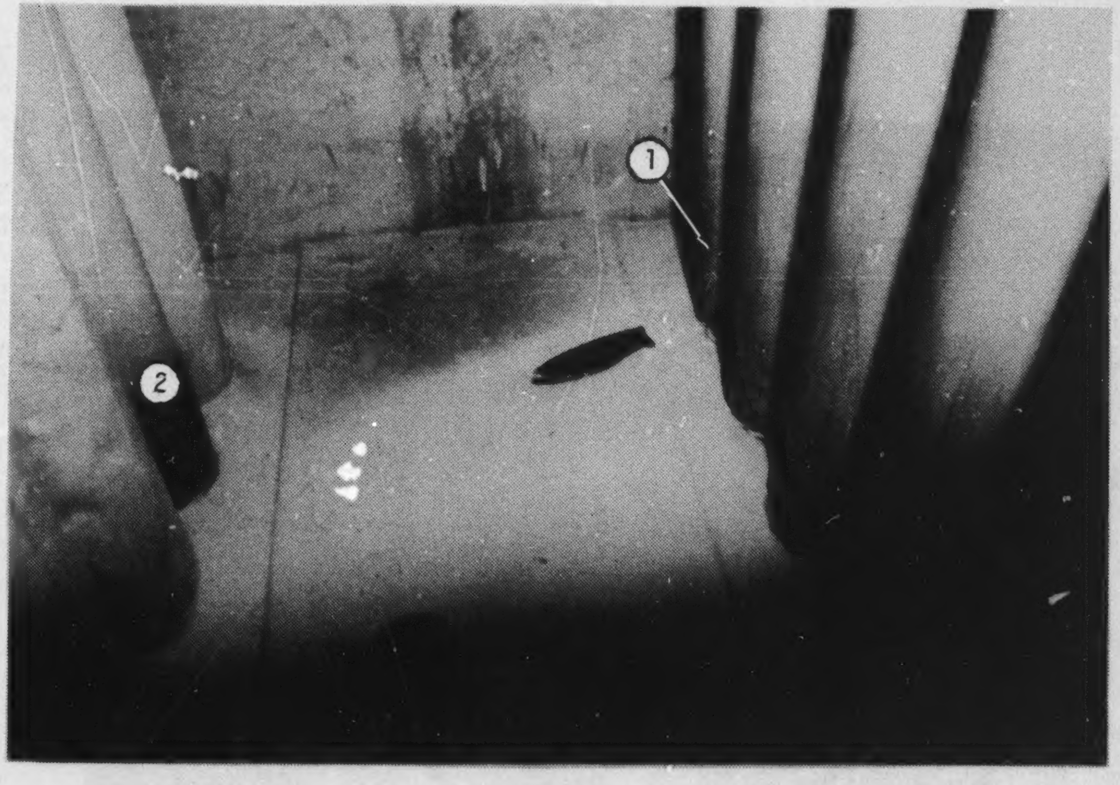

Figure 6-6. Pinhole leak (1) forms a dust jet on the floor near a shaker-type fabric filter. [Note that the darkened bag (2) is being abraded by dust from the pinhole leak and it too will ultimately fail.] (Courtesy of PEI Associates, Inc.)

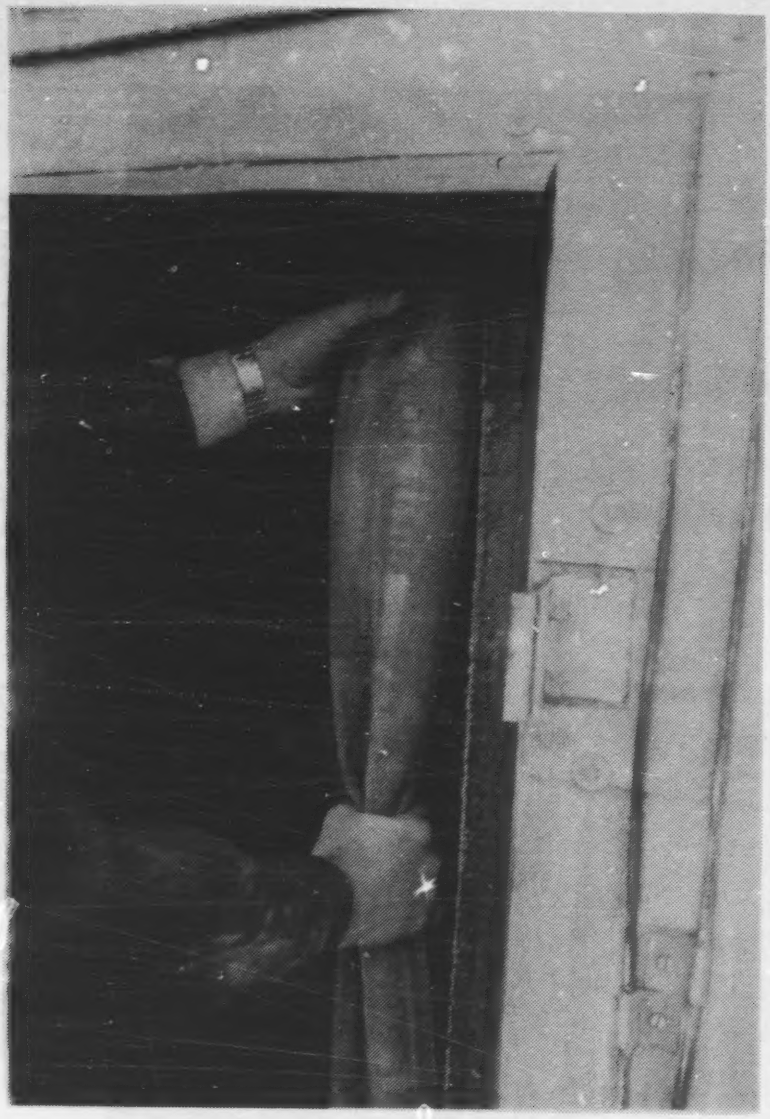

Figure 6-7. Checking for excessive build-up and poorly tensioned bags in a reverse-air fabric filter. This bag passed both tests. (Courtesy of PEI Associates, Inc.)

The compressed air system should be inspected to ensure that it is installed properly and that it has aftercoolers, automatic condensate traps, and filters as necessary for proper operation.[4] The inspection should determine whether there is any water or rust deposits in the compressed-air system that would cause the system to malfunction. One quick method of checking whether the system has water or rust deposits is to carefully open the valve on the blowdown system and observe whether any water or other material is being expelled through the valve. If the system has oil traps, the traps also can be visually inspected to determine if any water or other material is retained in the trap.

6.5 RECORDKEEPING

The key to a good inspection and maintenance program is recordkeeping. A record of all inspections should be maintained in the form of inspection reports. Bag failure records were discussed in section 4. A brief narrative discussion of the major deficiencies that were discovered and a recommended course of action should also be prepared and filed with the inspection report form.

6.6 SUMMARY

To summarize the preceding discussions, the following major items should be addressed during the inspection of any fabric filter system:

1) Dust Capture and Transport System

The inspector should check all movable or stationary hoods and evaluate the capture velocities, dust accumulation, static pressure, condition of cleanout traps, integrity of ductwork, fan wear, and leaks or fugitive dust emissions.

2) Fabric Filter System

The following are the major elements that should be evaluated during the inspection of the fabric filter system:[4]

- Parameter monitors--including opacity or broken bag detectors; manometers for pressure drop across fabric, compartments, or entire collector; indicators for cleaning sequence, cycle time, compartments off line, temperature, volume flow, air-to-cloth ratio, moisture, pulse-jet header pressure, and reverse-air flow.

- Baghouse exterior--cleaning system operation; cleaning method; overall condition of exterior housing, including structural members, access doors, and gaskets, reverse air fan operation, and shaker mechanism. External inspection will reveal visual evidence of corrosion; warping of panels; faulty or missing gaskets; loose bolts; and noise, odor, or elevated temperatures, which are indicators of worn bearings, overstressed fan belts, and electric motor problems.
- Baghouse interior (if deemed necessary and is feasible)--condition of bags: tears, pinholes, and sagging (inadequate tension). A sagging or slack bag can result in the bag folding over the bottom thimble connection and creating a pocket in which accumulated dust can rapidly abrade and tear the fabric. Slackness also prevents effective cleaning action with both reverse-flow or mechanical shaking systems. Dust seepage or bleeding and/or pinhole leaks are evidenced by dust deposits on the clean side of the fabric. Staining and stiffening of the dirty fabric indicates excessive caking caused by moisture condensation or chemical reactions. The latter condition leads to fabric blinding and excessive pressure loss as well as to fabric failure. More than a 1/4-inch dust layer on floor plates or isolated piles of dust suggests excess seepage and/or torn or missing bags. Inspection of the inlet plenum, including bag interior, will reveal any excess dust buildup on bags and distribution plates. As a "rule-of-thumb" for smaller baghouses, if the amount of dust on a bag after cleaning is more than twice the weight of the new (unused) bag, insufficient cleaning is indicated. The condition of solenoid valves, poppet valves, mechanical linkages, and bag clamps are also indicated.[11]

Figure 6-8 lists the major data elements that should be obtained and evaluated in a routine diagnostic inspection of a pulse-jet fabric filter. Figure 6-9 lists the major data elements that should be obtained and evaluated in a routine and a diagnostic inspection of a reverse-air and shaker fabric filter.

° Routine Inspection Data

Stack	Average Opacity Duration and Timing of Puffs
Fan	None
Fabric Filter	Inlet and Outlet Gas Temperatures Inlet and Outlet Static Pressures Presence or Absence of Clean Side Deposits Air Reservior Pressure Audible Checks for Air Inleakage Qualitative Solids Discharge Rate

° Diagnostic Inspection Data

Stack	Average Opacity Peak Opacity During Puffs Duration and Timing of PUffs
Fan	Inlet Gas Temperature Speed Damper Position Motor Current
Fabric Filter	Inlet Gas Temperature Outlet Gas Temperature Inlet Static Pressure Outlet Static Pressure Inlet O_2 and CO_2 Content (Combustion Sources) Outlet O_2 and CO_2 Content (Combustion Sources) Qualitative Solids Discharge Rate Air Reservoir Pressure Frequency of Cleaning Presence or Absence of Clean Side Deposits Audible Air Infiltration

Figure 6-8. Routine and diagnostic inspection data for pulse-jet fabric filters.[20]

° Routine Inspection Data

Stack	Average Opacity Opacity During the Cleaning Cycles (for each compartment)
Fabric Filter	Inlet and Outlet Static Pressures Inlet Gas Temperature Rate of Dust Discharge (Qualitative Evaluation) Presence or Absence of Audible Air Infiltration Presence or Absence of Clean Side Deposits Ripping Strength of Discarded Bags

° Baseline and Diagnostic Inspection Data

Stack	Average Opacity Opacity During the Cleaning Cycles (for each compartment)
Fabric Filter	Date of Compartment Rebagging Inlet Static Pressure (Average) Outlet Static Pressure (Average) Minimum, Average, and Maximum Gas Inlet Temperatures Average O_2 and CO_2 Concentrations (Combustion Sources Only) Time to Complete a Cleaning Cycle of all Compartments Length of Shake Period Length of Null Period Bag Tension (Qualitative Evaluation) Rate of Dust Discharge (Qualitative Evaluation) Presence or Absence of Audible Air Infiltration Presence or Absence of Clean Side Deposits
Stack Test	Emission Rate Gas Flow Rate Stack Temperature O_2 and Co_2 Content Moisture Content
Fan	Fan Speed Fan Motor Current Gas Inlet and Outlet Temperatures Damper Position

Figure 6-9. Routine and Diagnostic Inspection Data for reverse air shaker fabric filters.[20]

REFERENCES FOR SECTION 6

1. Billings, C. E., and J. E. Wilder. Handbook of Fabric Filter Technology, Vol. 1. GCA/Technology Division, Bedford, Massachusetts. EPA-APTD 0690 (NTIS PB-200-648), December 1970.

2. Reigel, S. A., and G. D. Applewhite. Operation and Maintenance of Fabric Filter Systems. In: Operation and Maintenance for Air Particulate Control Equipment. Young, R. A. and F. L. Cross, eds. Ann Arbor Science, Ahn Arbor, Michigan, 1980.

3. Cross, F. L., and H. E. Hesketh, eds. Handbook for the Operation and Maintenance of Air Pollution Control Equipment. Technomic Publishing Co., Inc., Westport, Connecticut, 1975.

4. Roeck, D. R., and R. Dennis. Fabric Filter Inspection and Evaluation Manual. Prepared for U.S. Environmental Protection Agency under Contract No. 68-01-6316. 1980.

5. Cheremisinoff, P. N., and R. A. Young, eds. Air Pollution Control and Design Handbook, Part 1. Marcel Dekker, Inc., New York, 1977.

6. McKenna, J. D., and G. P. Greiner. In: Air Pollution Control Equipment - Selection, Design, Operation and Maintenance. Theodore, L. and A. J. Buonicore, eds. Prentice Hall Inc., Englewood Cliffs, New Jersey, 1981.

7. Stern, A. C., ed. Air Pollution, Volume IV, Engineering Control of Air Pollution. 3rd Ed., Parts A and C Academic Press, Inc., New York, San Francisco, London, 1976.

8. Kraus, M. N. Baghouses: Selecting, Specifying and Testing Industrial Dust Collectors. Chem. Eng., 86(9):133-142, 1979.

9. Industrial Gas Cleaning Institute (IGCI). Operation and Maintenance of Fabric Collectors, Publication No. 53. Suite 304, 700 N. Fairfax Street, Alexandria, Virginia.

10. Beachler, D. S., and M. Peterson. APTI Course SI:412 Baghouse Plan Review, Student Guidebook. EPA No. 450/2-83-005, April 1982.

11. W. W. Sly Manufacturing Co. Instruction Book, No. 693, Post Office Box 5939, Cleveland, Ohio, 1980.

12. Mikro-Pul Corp. Owner's Manual Micro-Pulsaire Dry Dust Collector, SD379a. Section VII C - Troubleshooting. 10 Chatham Road, Summit, New Jersey, 1980.

13. Mikro-Pul Corp. Owner's Manual, Micro-Pulsaire Dry Dust Collector, SD578, Section VII C Troubleshooting. 10 Chatham Road, Summit, New Jersey, 1980.

14. Zurn Industries. Start-Up Procedure. Operation and Proposed Maintenance Instructions. Air Systems Division, Post Office Box 2206, Birmingham, Alabama, 1980.

15. Flex-Kleen/Research-Cottrell. Installation, Operating and Maintenance Manual. Bulletin 399. 222 South Riverside Plaza, Chicago, Illinois, 1980.

16. Ecolaire Environmental Co. Operation and Maintenance Literature. 380 Civic Driver, Pleasant Hill, California, 1980.

17. Campbell, P. R. Maintaining Proper Tension. Power, 124(2):92, 1980.

18. Reigel, S. A. Fabric Filtration Systems, Design, Operation, and Maintenance.

19. PEDCo Environmental, Inc. Development of Pilot Inspection System for Virginia Air Pollution Control Board. Prepared for U.S. Environmental Protection Agency under Contract No. 68-01-6310, Work Assignment No.28, April 1983.

20. Engineering - Science. Field Inspection Notebook Prepared for the U.S. Environmental Protection Agency under Contract No. 68-01-6312, Work Assignment No. 62 and 69, October 1983.

SECTION 7

SAFETY

The safety of plant personnel and agency inspectors during all aspects of fabric filter O&M is of ultimate importance. Areas of concern include confined area entry (oxygen deficiency and toxic gases), hazardous materials (dust, metals, etc.), chemical burns, eye injury, and normal industrial safety concerns such as moving equipment, falls, etc. With regard to fabric filters, many of these concerns occur simultaneously and in a confined area, which presents the potential for serious injuries to personnel. With proper planning, safety equipment, and established procedures, operation and maintenance and inspections can be performed safely without risk of injury.

Many of the potential hazards and proper procedures for addressing them are discussed in the following subsections. Further information on confined area entry and manufacturers of safety appliances can be found in specific vendor maintenance manuals on installed units and in Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) publications.

7.1 HOPPER ENTRY

Fabric filter hoppers present special safety hazards. It is recommended that hopper doors be interlocked and that the hopper doors be opened only after the unit has been shut down. For economic reasons, however, many companies substitute the use of padlocks for the key-interlock system. In principle, the use of padlocks is equally as safe if proper procedures are followed. The tendency, however, is to remove the lock and open hopper doors prematurely to quick-cool a unit or clear a hopper pluggage.

The danger in opening doors comes from the discharge of material impounded in the hopper. Dust that has accumulated in valleys or corners may break loose during entry into the hopper and fall on the inspector, causing minor injury or, in some cases, serious injury or suffocation by burying him or her. The doors on hoppers must be opened very carefully, and care must be taken to ensure that no accumulation of collected dust is impounded behind the inner door.

Entry into hoppers for purposes other than maintenance should be avoided. Maintenance that can be conducted outside of the hopper should be attempted first. If entry is necessary, the bags should be thoroughly cleaned and then steps should be taken to dislodge and discharge dust from the hopper before entry. This can be accomplished by mechanical vibration (vibrators, hammers, etc.) or poking, prodding, or air lancing. Removal of accumulated dust should never be attempted from inside the hopper. This material may become dislodged and move en masse into the inlet or outlet field hoppers and completely fill the hopper.

All hopper doors should be equipped with safety chains or double latches to prevent complete opening upon release. This will slow the loss of material or ash in the event of accidental opening of a full hopper.

Most hopper inner doors have design features that, if properly used, will ensure that no door is opened when dust is impounded behind it. First, a pipe coupling with a plug should be installed in the door; removal of the plug allows visual verification of dust impoundment. Second, a pressure-type latch should be used that allows a portion of the door seal to be released and causes a gap between the door and sealing jam. This partial release will allow accumulated dust to flow out and indicate a partially full hopper without the possibility of the door being fully opened.

A normal practice is to discharge the hoppers fully before entry and after each period of dust removal. Whether the hopper is full may be determined by striking the door with a hammer. An empty hopper door will resound with a ring; a full hopper will produce a dull thud.

A further warning in connection with hopper entry involves the use of hand grips, foot holds, etc., inside the hopper. Because of the possibility of dust buildup on protruding objects, manufacturers have avoided the use of handholds and footholds in hopper interiors. Thus, the steep valley angles and dust layer create a potential for a fall and injury when entering the door. Temporary ladders and handholds may be installed and used when needed. Because of the angles and small door openings, back injuries are the most common (other than abrasions). Outside access equipment (scaffolds, ladder, handholds, etc.) should be installed in a manner that minimizes the awkward nature of hopper door entry. Also, if nuclear hopper level detectors are used, the radiation source (beam) should be shielded from the outside before the hopper is entered.

Hopper evacuation systems (screws, drag chains, agitators, etc.) should not be operated when persons are inside the hopper area or in an area from which they could fall into the hoppers. Dust accumulation that is discharged into the hopper can be considered a live bottom with moving equipment. The dust becomes fluid and creates treacherous footing. Scaffolds on which persons are standing may shift and float, and that person(s) may become engulfed in the collected material.

7.2 CONFINED AREA ENTRY

A confined space is an enclosure in which dangerous air contamination cannot be prevented or removed by natural ventilation through opening of the space. Access to the enclosed area may be restricted such that it is difficult for personnel to escape or be rescued. The most common examples of a confined space are storage tanks, tank cars, or vats. Depressed areas (e.g., trenches, sumps, wells) also may have poor ventilation and be considered a confined space. A fabric filter system falls under the general definition of confined space, and as such, requires special procedures and precautions with regard to entry.

Potential dangers of confined space fall into three categories: oxygen deficiency, explosion, and exposure to toxic chemicals and agents. Personnel entering the fabric filter for inspection or maintenance must assess the risks and potential dangers in each category and follow specific safety precautions.

7.2.1 Oxygen Deficiency

Oxygen deficiency is the most common hazard. Any gas generated in a confined space displaces the atmosphere and reduces the oxygen content below the normal value of 20.9 percent. Out-gassing of combustible gases (methane, H_2S, organic vapors, etc.) from collected particulate matter can result in local pockets with reduced oxygen levels. Further, application of the fabric filter to combustion sources (e.g., utility boilers, industrial boilers, cement kilns, incinerators) produces an atmosphere that is extremely low in oxygen (2 to 10 percent). Purging of the unit during cooling does not always completely replace the flue gases with ambient air, and local pockets may remain.

Reduction of oxygen pressure below normal conditions has increasingly severe effects on a person and eventually leads to death. Oxygen levels of less than 16.5 percent result in rapid disability and death. Table 7-1 shows the effects of reduced oxygen concentrations for various lengths of time. Because of the subtle effects of oxygen deficiency, the average person does not recognize the symptoms and may ignore the danger. By the time the person does recognize the problem, he may no longer be able to remove himself from the dangerous environment.

7.2.2 Explosion

Explosive atmospheres can be created in confined spaces by the evaporation of volatile components or improper purging of the fabric filter when the process is shut down. Three elements are necessary to initiate an explosion: oxygen, a flammable gas, vapor or dust, and an ignition source. A flammable atmosphere is defined as one in which a gas concentration is between two extremes: 1) the lower explosive limit (LEL) and the upper explosive limit (UEL). A mixture of gas and oxygen in a concentration between these values can explode if a source of ignition is present.

Possible sources of ignition include cigarettes, matches, welding and cutting torches, and grinding equipment. The best means of preventing explosion is to dilute the flammable gas below the LEL by ventilation. It is not safe to assume that a source of ignition can be eliminated and to allow work to continue in a potentially explosive atmosphere.

TABLE 7-1. EFFECTS OF VARIOUS LEVELS OF OXYGEN ON PERSONS[a]

Concentration, percent	Duration	Effect[b]
20.9	Indefinite	Usual oxygen content of air
19.5	Not stated	Minimum oxygen content for oxygen deficient atmospheres (OSHA Standards)
16.5	Not stated	Lowest limit of acceptable standards reported in literature for entry without air-supplied respirators
12-16	Seconds to minutes	Increased pulse and respiration, some coordination loss
10-14	Seconds to minutes	Disturbed respiration, fatigue, emotional upset
6-10	Seconds	Nausea, vomiting, inability to move freely, loss of consciousness
Below 6	Seconds	Convulsions, gasping respiration followed by cessation of breathing and cardiac stand-still

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[a] Data for correspondence of Robert A. Scala, Ph. D., REHD, Exxon Corporation, March 26, 1974.

[b] Effects - Only trained individuals know the warning signals of a low oxygen supply. The average person fails to recognize the danger until he is too weak to rescue himself. Signs include an increased rate of respiration and circulation that accelerate the onset of more profound effects including loss of consciousness, irregular heart action, and muscular twitching. Unconsciousness and death can be sudden.

Work in a confined area may release flammable gases, which can increase in concentration. Constant ventilation should be provided to maintain the concentration below the LEL.

Because many vapors are heavier than air, pockets of flammable gases may develop. An effective monitoring program checks concentrations at multiple locations and times during the exposure period.

7.2.3 Exposure to Toxic Chemicals and Agents

Depending on the application of the fabric filter, collected dust may contain toxic chemicals or harmful physical agents. These compounds may exist in the system or be created as a result of operations in the confined area. Inhalation, ingestion, or skin contact have adverse health effects. Most agents have threshold limit doses below which harmful effects do not occur. Exposure above these threshold doses can cause acute or chronic symptoms, depending on the compound. A quantitative assessment of each compound and the threshold dose levels must be made before anyone is allowed to enter the fabric filter. Typical toxic chemicals or species in the fabric filter environment can include arsenic, cadmium, beryllium, lead, alkali, and acids. Table 7-2 lists the allowable concentrations for entry into confined spaces for several compounds.

TABLE 7-2. ALLOWABLE CONCENTRATIONS FOR ENTRY INTO CONFINED SPACES

Agent[a]	Without air-supply equipment	With air-supply equipment	No entry permitted[b]
Hydrocarbons	1% LEL max.	20% LEL max.	Above 20% LEL
Oxygen	19.5-23.5%	16.5% min.	Below 16.5%
H_2S	10 ppm max.	300 ppm	>300 ppm
Carbon monoxide	30 ppm max.	200 ppm	>200 ppm
SO_2	5 ppm max.	500 ppm	>500 ppm

[a] If other contaminants are present, an industrial hygienist should be consulted for the appropriate allowable limits.

[b] Work may be performed in oxygen-free atmospheres if backup systems are available, such as air-line respirators, self-contained breathing apparatus, and an emergency oxygen escape pack.

As noted in Table 7-2, entry may be permitted within certain limitations provided the person is equipped with appropriate approved respiratory protection. An assessment of the hazard, concentration, permissible exposure, and protective equipment must be made before anyone is allowed to enter a confined space.

Each facility must establish a confined-space entry policy that includes recognition of the hazards, atmospheric testing and analysis, ventilation requirements, selection and use of protective equipment, training and education of personnel, and administrative procedures.

An important component of the program is recognition of the potential hazard, which requires complete knowledge of the industrial process and wash area. A cursory examination cannot prevent serious deficiencies; detailed analysis is therefore recommended.

The second policy component involves ambient air monitoring. An initial certification of gaseous concentrations must be made before entry is permitted. This certification must be made by a qualified safety officer with properly calibrated and maintained equipment. In general, a permit to enter (with a time limit) may be issued and displayed at the point of entry. Assuming that oxygen and gas levels do not change with time can be dangerous; an effective program should include periodic reevaluations of concentrations after initial entry.

Hazard Recognition--

Each worker should be trained in use of protective equipment, potential hazards, early warning signs of exposure (symptoms), and rescue procedures (first aid, CPR, etc.). It is most important that each person recognize that multiple fatalities can occur if proper rescue procedures are not followed. If a worker is affected within the confined area and cannot remove himself, rescue personnel must not enter the area without complete self-contained breathing equipment. If the first worker is affected by an unknown agent, it is highly probable that rescue personnel will be similarly affected unless they have the proper protective equipment. Because the causal agent is not known, maximum protection must be used during the rescue attempt.

Atmospheric Testing and Analysis--

Gas monitoring usually is conducted to determine the percentage of oxygen, the percentage of lower explosive limit (hexane/methane, heptane, etc.), hydrocarbon concentration (in parts per million), and carbon monoxide levels (in parts per million). If hydrogen sulfide or other toxic gases are suspected, additional analyses may be conducted with detection tubes or continuous gas samplers. The use of continuous gas samplers with an audible alarm is recommended. The initial measurements should be performed according to the following suggested procedures.

1. Remaining outside, a gas tester should check the vessel's oxygen content, explosivity, and toxic chemical concentration by first sampling all entry ports and then use probes to sample inside the space. Caution should be used when testing for combustible gases, as many meters need an oxygen level close to ambient levels to operate correctly. This is one reason that the space should be purged and vented before testing. Voids, subenclosures, and other areas where pockets of gas could collect should also be tested.

2. When initial gas test results show that the space has sufficient oxygen, the gas tester can enter the space and complete the initial testing by examining areas inaccessible from outside the shell. He/she should wear an air-supplied positive-pressure respirator during these measurements. Special care should be taken to test all breathing zone areas.

3. If the results of the initial tests show that a flammable atmosphere still exists, additional purging and ventilation are required to lower the concentration to 10 percent of the LEL before entry may be permitted.

4. If testing shows an oxygen-deficient atmosphere or toxic concentrations, all personnel entering the space must use an appropriate air-supplied respirator.

After the initial gas testing has been performed, dust, mists, fumes, and any other chemical agents present should be evaluated by either an industrial hygienist or a trained technician. The results will indicate if additional control measures are necessary. Physical agents such as noise, heat, and radiation also must be evaluated, and if any are present, the appropriate control measures (e.g., ear protection or rotating employees), should be instigated.

The specified respiratory protection should be based on the hazard assessment, i.e., the type of contaminant, its concentration, and the exposure time. The type of respiratory equipment required for each species is specified by NIOSH.

Respirators include basic particle-removing devices (dust, aerosol, mist, etc.), air-purifying respirators (gas, vapors, etc.), and air-supplying respirators (air-line, self-contained).

7.3 WORKER PROTECTION

7.3.1 Eye Protection

Dust collected by fabric filters is very fine and usually contains a high percentage of particles less than 5 mm. The particles may be sharp-edged or crystalline in nature. Because all surfaces in the fabric filters are coated with dust, which may be easily dislodged and suspended during internal inspections, protection is necessary to prevent dust from entering the eyes. Goggle type protection is generally not effective because of the inability of the frames to form a tight seal against the worker's face. Effective eye protection consists of full-face protection or a snorkling mask.

Eyes also may be subjected to chemical damage as a result of the dust composition or species condensed onto the dust particles. The most common active agents are sulfuric acid on fly ash particles and alkali agents in cement applications. Each plant should collect samples of fabric filter dust and specify eyewash solutions suitable for removing or neutralizing the active components. Table 7-3 summarizes the kinds of applications where potential eye hazards may exist.

TABLE 7-3. APPLICATIONS PRESENTING POTENTIAL EYE HAZARDS

Application	Potential active species	pH
Fly ash	Sulfuric acid	Acid
Cement	Alkali (NaOH, Na_2SO_4, K_2SO_4, etc.)	Alkaline
Municipal incineration	Hydrochloric acid	Acid
Copper converter	Sulfuric acid	Acid

7.3.2 Hearing Protection

The fabric filter housing is a large open area with metal walls that tend to magnify and reflect sound energy. When inspectors are inside the unit, proper hearing protection should be used to limit sound levels to maximum permitted exposure. Many types of hearing protection devices (cotton, premolded inserts, foam, ear muffs, etc.) are available; selection depends on individual preference and expected sound levels.

Limits of worker exposure to noise are based on both duration of exposures and sound levels (dBA). Permissible levels for intermittent noise and nonimpulsive levels are presented in Tables 7-4 and 7-5.

7.3.3 Skin Irritation

Depending on its composition, the dust collected in the fabric filter can be acidic, alkaline, hydroscopic, or abrasive. When it contacts the skin, this dust can cause burns or irritation. Workers can limit skin contact area and thus prevent potential irritation by wearing long-sleeved shirts and gloves during internal inspections. Depending on temperature conditions and activity levels, coveralls or other full covering may be worn.

TABLE 7-4. MAXIMUM PERMISSIBLE SOUND LEVEL FOR INTERMITTENT NOISE[a]
(A-weighted sound level, dBA)

	Number of occurrences per day						
Total time/8 hours	1	3	7	15	35	75	≥160
8 hours	89	89	89	89	89	89	89
6 hours	90	92	95	97	97	94	93
4 hours	91	94	98	101	103	101	99
2 hours	93	98	102	105	108	113	117
1 hour	96	102	106	109	114	125	125
½ hour	100	105	109	114	125		
¼ hour	104	109	115	124			
8 minutes	108	114	125				
4 minutes	113	125					
2 minutes	123						

[a] Source: The Industrial Environment - Its Evaluation and Control. NIOSH, 1973, p. 327.

TABLE 7-5. THRESHOLD LIMIT VALUES FOR NONIMPULSIVE NOISE (ACGIH)[a]

Duration, hours/day	Permissible sound level, dBA
8.00	90
6.00	92
4.00	95
3.00	97
2.00	100
1.50	102
1.00	105
0.75	107
0.50	110
0.25	115

[a] Source: The Industrial Environment - Its Evaluation and Control. NIOSH, 1973, p. 327.

7.3.4 Thermal Stress

Thermal stress associated with inspections and maintenance of a fabric filter and its components must be considered in defining the time required for repairs. Because of the dusty, humid conditions and limited access, thermal effects may be severe. Also, if limited time is available for purging and cooling the unit, entry may have to be made under elevated temperatures.

The thermal stress placed on the worker is a function of several variables, such as air velocity, evaporation rate, humidity, temperature, radiation, and metabolic rate (work). In effect, the stress is indicated by the need to evaporate perspiration.

A Heat Stress Index developed by Belding and Hatch (1955)* incorporates environmental heat [radiation (R) and convection (C), and metabolic (M)] into an expression of stress in terms of requirement for evaporation of perspiration. Algebraically the function may be stated as follows:

$$M + R + C = E \text{ req.}$$

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*Belding and Hatch. Index for Evaluating Heat Stress in Terms of Resulting Physiologic Strains. Heating, Piping and Air Conditioning, 1955.

The resulting physiological strain is determined by the ratio of stress (E req.) to the maximum capacity of the environment (E max.). The resulting value is defined as the Heat Stress Index (HSI), which is calculated as:

$$HSI = \frac{E\ req.}{E\ max.} \times 100$$

The values E req. and E max. may be calculated at the maximum exposure time based on the HSI defined. Generally, HSI maximum acceptable values are established for an 8-hour work day.

Table 7-6 indicates expected physiological and hygienic implications of an 8-hour exposure at various heat-stress levels.

A nomograph may be used to evaluate acceptable exposure times under various conditions. Figure 7-1 shows the methodology for calculating exposure time. Constants and variables used in the nomograph are as follows:

$$R = 17.5\ (Tw - 95)$$

$$C = 0.756\ V^{0.6}(Ta - 95)$$

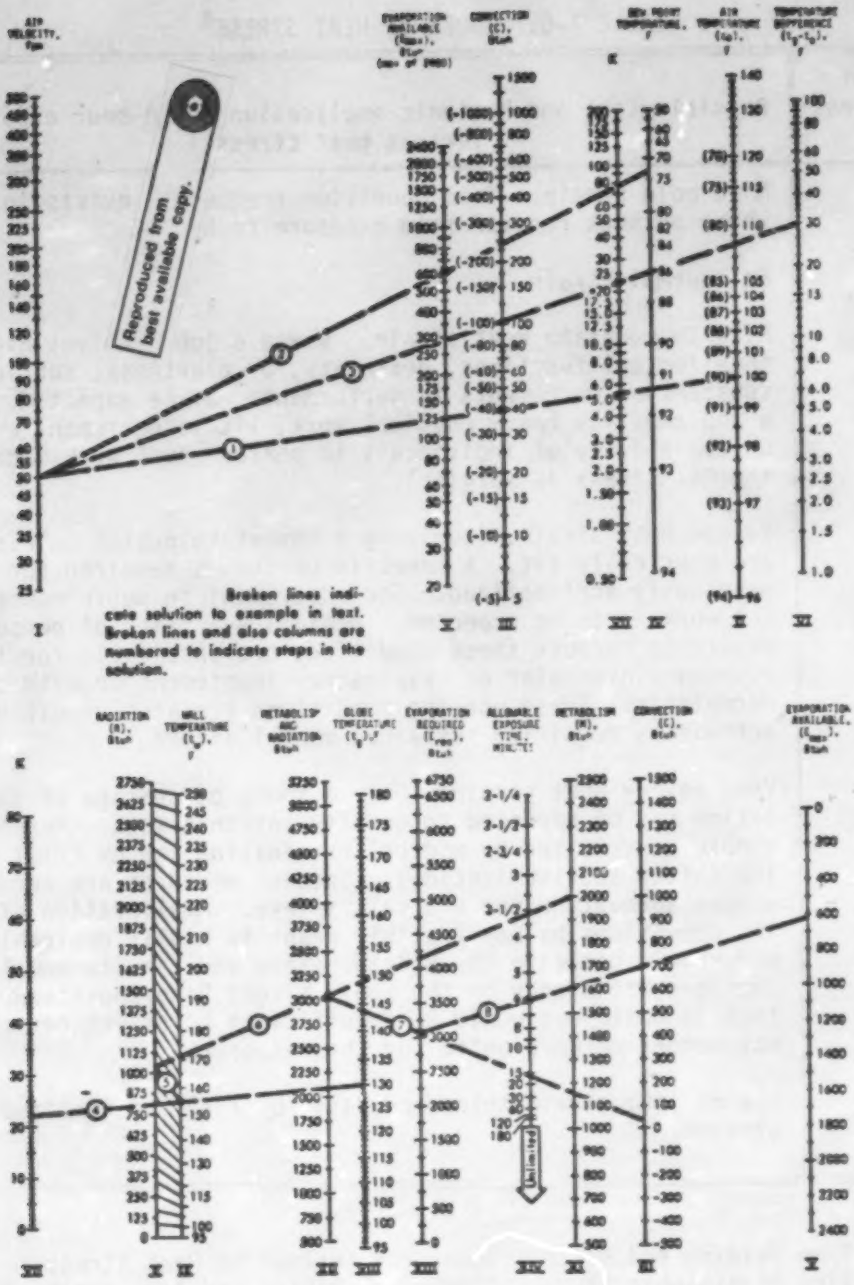
$$E\ max. = 2.8\ V^{0.6}\ (42\text{-}PWa)$$

where R = radiant heat exchange, Btu/h
C = convective heat exchange, Btu/h
E max. = max. evaporative heat loss, Btu/h
Tw = mean radiant temperature, °F
Ta = air temperature, °F
V = air velocity, ft/min
PWa = vapor press., mm Hg
Twb = wet bulb temperature, °F
M = metabolic rate, Btu/h
Tg = globe temperature, °F

TABLE 7-6. INDEX OF HEAT STRESS[a]

Index of Heat Stress (HSI)	Physiological and hygienic implications of 8-hour exposures to various heat stresses
-20 -10	Mild cold strain. This condition frequently exists in areas where persons recover from exposure to heat.
0	No thermal strain.
+10 20 30	Mild to moderate heat strain. Where a job involves higher intellectual functions, dexterity, or alertness, subtle to substantial decrements in performance may be expected. When a job requires heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
40 50 60	Severe heat strain, involving a threat to health unless persons are physically fit. A break-in period is required for those not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel is desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
70 80 90	Very severe heat strain. Only a small percentage of the population may be expected to qualify for this work. Personnel should be selected by medical examination and by trial on the job (after acclimatization). Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is highly desirable, and should decrease the health hazard and simultaneously increase efficiency on the job. Slight "indisposition" that in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
100	The maximum strain tolerated daily by fit, acclimatized, young persons.

[a] Adapted from Belding and Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiologic Strains," Heating, Piping and Air Conditioning, 1955.



Broken lines indicate solution to example in text. Broken lines and also columns are numbered to indicate steps in the solution.

Figure 7-1. Nomograph developed by McKarns and Brief incorporating the revised Fort Knox coefficients.

Source: McKarns, J. S., and R. S. Brief. Nomographs Give Refined Estimates of Heat Stress Index. Heating, Piping and Air Conditioning 38:113, 1966.

An example presented here illustrates the use of the nomograph under the following conditions: T_g = 130°F, T_a = 100°F, T_{wb} = 80°F, V = 50 ft/min, M = 2000 Btu/h and dew point = 73°F.

Step 1. Determine convection (c). Connect velocity (column I) with air temperature [(Ta) column II] and read c on column III.

Step 2. Determine E max. Connect velocity (column I) and dew point (column IV) and read E max. on column V.

Step 3. Determine constant K. Connect velocity (column I) with Tg-Ta (column VI) and read K on column VII.

Step 4. Determine Tw. Connect K (column VII) and Tg (column VIII) and read Tw on column IX.

Step 5. Extend line in step 4 to column X and read R.

Step 6. Connect R (column X) with M (column XI) and read R + M on column XII.

Step 7. Connect C (column III) with R + M (column XII) and read E req. on column XIII.

Step 8. Connect E max. (column V) with E req. (column XIII) and read allowable exposure time on column XIV.

Metabolic rate varies with exertion and work expended, and an estimate of M must be made for each effort expended in the fabric filter inspection or repair. Examples of M for several levels of activity are provided in Tables 7-7 and 7-8.

TABLE 7-7. HEAT PRODUCTION FOR VARIOUS LEVELS OF EXERTION

Activity	cal/m^2h
Sleeping	40
Sitting quietly	50
Working at a desk, driving a car, standing, minimum movement	80
Sentry duty, standing at machine while doing light work	100
Walking 2.5 mph on level, moderate work	150
Walking 3.5 mph or level, moderately hard work	200
Walking 3.5 mph on level with 45 lb load, hard work	300

[a] Adapted from: The Industrial Environment - Its Evaluation and Control. NIOSH, 1973.

TABLE 7-8. BODY HEAT PRODUCTION AS A FUNCTION OF ACTIVITY[a]

Activity	kcal/h
Rest (seated)	90
Light machine work	200
Walking, 3.5 mph on level	300
Forging	390
Shoveling	450-600
Slag removal	700

[a] Adapted from: The Industrial Environment - Its Evaluation and Control. NIOSH, 1973.

When the work involves lifting, pushing, or carrying loads; cranking; etc., the heat equivalent of the external work (W) is subtracted from the total energy output to obtain heat produced in the body (M).

SECTION 8
MODEL O&M PLAN

Generally, one or more individuals at a plant site are responsible for ensuring that a fabric filter is operated and maintained so that it meets design removal efficiencies for particulate matter and that the plant complies with regulatory emission limits.

Unfortunately, most O&M personnel do not receive in-depth training on the theory of fabric filter operation, diagnostic analysis, and the problems and malfunctions that may occur over the life of a unit. Plant personnel tend to learn about the operation of a specific unit and to gain operating experience as a result of day-to-day operating problems. This so-called "on-the-job" training can result in early equipment deterioration or catastrophic failures that could have been avoided.

This section presents the basic elements of an O&M program that will prevent premature fabric filter failure. This program is not all-inclusive, and it does not address all potential failure mechanisms. Nevertheless, it provides the user with enough knowledge to establish a plan of action, to maintain a reasonable spare parts inventory, and to keep the necessary records for analysis and correction of deficiencies in fabric filter operation.

The overall goal of an O&M plan is to prevent unit failures. In case failures do occur, however, the plan must include adequate procedures to limit the extent and duration of excess emissions, to limit damage to the equipment, and to effect changes in the operation of the unit that will prevent recurrence of the failure. The ideal O&M program includes requirements for recordkeeping, diagnostic analysis, trend analysis, process analysis, and an external and internal inspection program.

The components of an O&M plan are management, personnel, preventive maintenance, inspection program, specific maintenance procedures, and internal plant audits. The most important of these are management and personnel. Without a properly trained and motivated staff and the full support of plant management, no O&M program can be effective.

8.1 MANAGEMENT AND STAFF

Personnel operating and servicing the fabric filter must be familiar with the components of the unit, the theory of operation, limitations of the device, and proper procedures for repair and preventive maintenance.

For optimum performance, one person (i.e., a coordinator) should be responsible for fabric filter O&M. All requests for repair and/or investigation of abnormal operation should go through this individual for coordination of efforts. When repairs are completed, final reports also should be transmitted to the originating staff through the fabric filter coordinator. Thus, the coordinator will be aware of all maintenance that has been performed, chronic or acute operating problems, and any work that is in progress.

The coordinator, in consultation with the operation (process) personnel and management, also can arrange for and schedule all required maintenance. He/she can assign priority to repairs and order the necessary repair components, which sometimes can be received and checked out prior to installation. Such coordination does not eliminate the need for specialists (electricians, pipe fitters, welders, etc.), but it does avoid duplication of effort and helps to ensure an efficient operation.

Many fabric filter failures and operating problems are caused by mechanical deficiencies. These are indicated by changes in differential pressures and temperatures and by opacity readings. By evaluating process conditions, pressure and temperature readings, inspection reports, and the physical condition of the unit, the coordinator can evaluate the overall condition of the unit and recommend process modifications and/or repairs.

The number of support staff required for proper operation and maintenance of a unit is a function of unit size, design, and operating history. Staff requirements must be assessed periodically to ensure that the right personnel are available for normal levels of maintenance. Additional staff will generally be needed for such activities as a major rebuilding of the unit and/or structural changes. This additional staff may include plant personnel, outside hourly laborers, or contracted personnel from service companies or fabric filter vendors. In all cases, outside personnel should be supervised by experienced plant personnel. The services of laboratory personnel and computer analysts may also be needed. The coordinator should be responsible for final acceptance and approval of all repairs. Figure 8-1 presents the general concept and staff organizational chart for a centrally coordinated O&M program.

As with any highly technical process, the O&M staff responsible for the fabric filter must have adequate knowledge to operate and repair the equipment.

Many components of a fabric filter are not unique, and special knowledge is not required regarding the components themselves; however, the arrangement and installation of these components are unique in most applications, and special knowledge and care are necessary to achieve their optimum performance.

Many plants have a high rate of personnel turnover, and new employees are assigned to work on a fabric filter who may have had no previous contact with air pollution control equipment. To provide the necessary technical expertise, management must establish a formal training program for each employee assigned to fabric filter maintenance and operation.

An optimum training program should include the operators, supervisors, and maintenance staff. Changes in operation that affect temperature, oil or moisture content, acid dew point, and the particulate abrasiveness of the gas stream entering the unit have a detrimental effect on fabric filter operation. The process operator has control over many of these variables. An understanding of the cause-and-effect relationship between process conditions and the fabric filter can help to avoid many performance problems. Safety is an important aspect of any training program. Each person associated with the unit should have complete instructions regarding confined-area entry, first aid, and lock-out/tag-out procedures.

Thus, a typical fabric filter training program should include safety, theory of operation, a physical description of the unit, a review of subsystems, normal operation (indicators), and abnormal operations (common failure mechanisms), troubleshooting procedures, a preventive maintenance program, and recordkeeping.

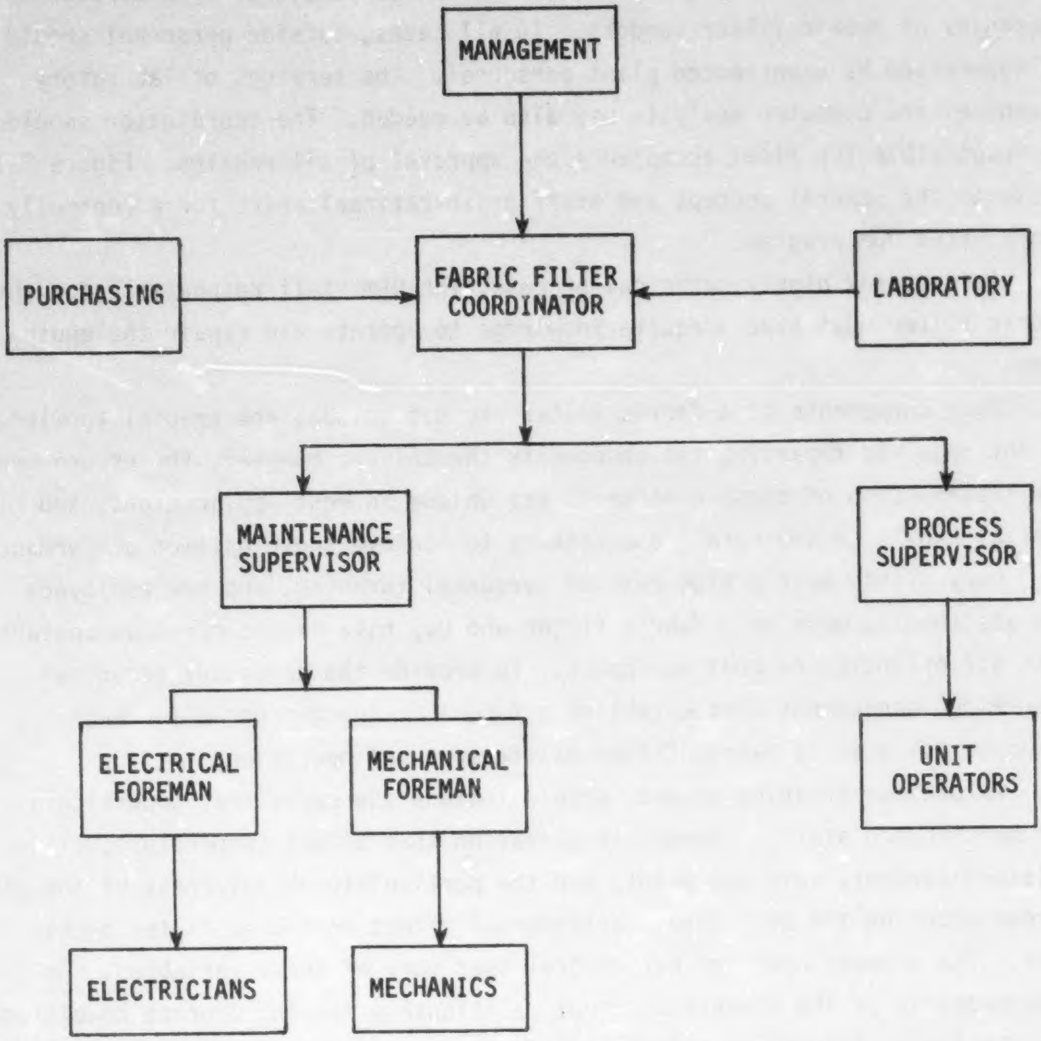


Figure 8-1. Organizational chart for centrally coordinated fabric filter O&M program.

The O&M program should emphasize optimum and continuous performance of the unit. The staff should never get the impression that less-than-optimum fabric filter performance is acceptable. Redundancy is established in the unit solely to provide a margin of safety for achieving compliance during emergency situations. Once a pattern is established that allows a less-than-optimum condition to exist (i.e., reliance on built-in redundancy), less-than-optimum performance becomes the norm, and the margin of safety begins to erode.

To reenforce the training program, followup written material should be prepared. Each plant should prepare and continually update a fabric filter operating manual and a fabric filter maintenance manual for each unit. A generic manual usually is not adequate because each vendor's design philosophy varies. The use of actual photographs, slides, and drawings aids in the overall understanding of the unit and reduces lost time during repair work.

Training material and courses available from manufacturers and vendors should be reviewed and presented as appropriate. Further, staff members responsible for each unit should attend workshops, seminars, and training courses presented by the Electric Power Research Institute (EPRI), the Portland Cement Association (PCA), EPA, and other organizations to increase the scope of knowledge and to keep current with evolving technology.

8.2 MAINTENANCE MANUALS

Specific maintenance manuals should be developed for each fabric filter at a source. The basic elements of design and overall operation should be specific to each fabric filter and should incorporate the manufacturer's literature and in-house experience with the particular type of unit. The manual should relate to the physical aspects of the unit. Descriptions should be brief and to the point; long narratives without direct application should be avoided.

Figure 8-2 presents a suggested outline for a typical manual. The manual should begin with such basic concepts as fabric filter description and operation. It can then continue with a section on component parts, which should include detailed drawings and an explanation of the function of each component and its normal condition.

A. FABRIC FILTER DESCRIPTION (GENERAL)
   1. Particulate Collection System
   2. Cleaning System
   3. Ash Removal System

B. DESCRIPTION OF OPERATION
   1. Collection Mechanisms
   2. Filter Cake Removal

C. SAFETY EQUIPMENT
   1. Self-Contained Breathing Apparatus
   2. Gas Monitoring Equipment
   3. Protective Clothing
   4. Eye and Ear Protection
   5. Gas Masks with Appropriate Filters
   6. Tags

D. COMPONENT DESCRIPTION
   1. Filter Media
   2. Cleaning System
   3. Housing
   4. Valves and Dampers
   5. Motors, Fans, and Belts
   6. Auxiliary Systems

E. INTERNAL INSPECTION AND MAINTENANCE
   1. Bags
      a. Worn, Abraded, Damaged Bags
      b. Condensation on Bags
      c. Tension
      d. Loose, Damaged, or Improper Bag Connection
   2. Inlet and Outlet Ducts
      a. Dust Buildup
      b. Baffle
   3. Hoppers
      a. Dust Buildup in Hoppers
      b. Hopper Heater Operation
   4. Corrosion on All Surfaces

F. EXTERNAL INSPECTION AND MAINTENANCE
   1. Cleaning System
      a. Operation Without Binding
      b. Loose or Worn Bearings
      c. Drive Components
      d. Solenoids, Pulsing Valves (Pulse-Jet)
      e. Compressed-Air System (Pulse-Jet)
      f. Damper Valves
   2. Air Leakage
      a. Expansion Joints
      b. Door Gaskets
      c. Cleaning System Penetrations
      d. Hoppers
   3. Interlocks
      a. Operation
      b. Lubrication
   4. Control Cabinet
      a. Cleanliness
      b. Loose Connections
      c. Air Filter

APPENDIX
   1. Inspection and Maintenance Checklist
   2. Layout Details

Figure 8-2. Outline for Fabric Filter Maintenance Manual.

The next section covers the internal inspection and maintenance procedure, which is extremely critical in maintaining performance. Periodic checks are necessary to maintain bag integrity, to remove accumulated ash deposits, and to prevent air inleakage. The section on external inspection and maintenance includes all supporting equipment, such as cleaning mechanisms, instrumentation, air compressors (where applicable), etc. Each of these sections should provide a procedure for evaluating the component. The manual should identify key operating parameters, define normal operation, and identify indicators of possible deviations from normal condition. Key operating parameters include temperature, pressure, cleaning cycle, opacity, or other parameters that can be used to establish the basic operating condition of the unit.

After evaluation of conditions, a procedure must be presented to replace, repair, or isolate each component. Unless a proper procedure is followed, the corrective action could result in further damage to the unit, excessive emissions, or repeated failure.

8.3 OPERATING MANUALS

Whereas maintenance manuals are designed to facilitate physical repairs to the fabric filter, operating manuals are needed to establish an operating norm or baseline for each unit. Maintenance of the physical structure cannot ensure adequate performance of the unit because gas stream conditions such as temperature, gas composition, and gas volume can cause premature bag failure and rapidly decrease collection efficiency.

The operating manual should parallel the maintenance manual in terms of introductory material so that the operators and maintenance personnel have the same basic understanding of the components and their function and of the overall operating theory. Additional information should be provided on the effects of major operating variables such as gas volume, gas temperature, and pressure drop. The manual also should discuss the effects of air inleakage on the bags, potential condensation problems, and the points where inleakage may occur (hoppers, doors, expansion points, etc.). Figure 8-3 presents an outline for an operating manual.

A. DESCRIPTION OF FABRIC FILTERS
   1. Particulate-Collection System
   2. Cleaning System
   3. Dust Removal System
B. DESCRIPTION OF OPERATION
   1. Collection Mechanisms
   2. Filter Cake Removal
C. OPERATIONAL FACTORS
   1. Gas Volume
      a. Excess Air
      b. Air Inleakage
         (1) Hoppers
         (2) Access Doors
         (3) Expansion Joints
         (4) Test Ports
         (5) Process Points
   2. Gas Temperature
      a. High Temperature
      b. Low Temperature
         (1) Acid and Moisture Dewpoint
   3. Differential Pressure
      a. High
      b. Low
   4. Opacity
D. ASH-REMOVAL-SYSTEM MALFUNCTION
   1. Plugged Hopper
   2. Low Vacuum
      a. Excess Air Inleakage
      b. Valves Stuck Open
E. STARTUP
   1. Safety Check
   2. Cleaning System On
   3. Ash Removal System On
   4. Hopper Heaters On
G. SHUTDOWN
   1. System Purged
   2. Hoppers Emptied
   3. Cleaning System Turned Off
   4. If Long Outage, Compressor, Hopper Heaters, and Dust-Removal System Turned Off

Figure 8-3. Fabric Filter Operating Manual outline. (Courtesy of PEI Associates, Inc.)

With regard to fuel combustion sources, the manual should discuss the effects of such process variables as burner conditions, burner alignment, and pulverizer fineness, which change the ash particle properties and size distribution. An expected normal range of values and indicator points should be established as reference points for the operator.

Startup and shutdown procedures should be established, and step-by-step instructions should be provided to ensure sequenced outage of equipment to aid in maintenance activities and to eliminate startup problems.

8.4 SPARE PARTS

An inventory of spare parts should be maintained to replace failed parts as needed. Because all components or subassemblies cannot be stocked, a rational system must be developed that establishes a reasonable inventory of spare parts. Decisions regarding which components to include in the spare parts inventory should be based on the following:

1. Probability of failure
2. Cost of components
3. Replacement time (installation)
4. Whether the part can be stored as a component or subassembly (i.e., shaker assembly vs. individual components)
5. In-house technical repair capabilities
6. Available space

The probability of failure can be developed from outside studies (e.g., EPRI), vendor recommendations, and a history of the unit. It is reasonable to assume that components subjected to heat, dust, weather, or wear are the most likely to fail. Components of this type are no different from those in process service, and reasonable judgment must be used in deciding what to stock. Maintenance staff members should be consulted for recommendations concerning some items that should be stocked and the number required. Adjustments can be made as operating experience is gained. Items that fall into this category include solenoids, drive belts, tension springs, shaker motor drives, and level indicators.

Another factor in defining a spare parts inventory is the cost of individual components. Although stocking bags or door seal components are not costly, stocking a spare compressor can be quite costly. Maintaining an extensive inventory of high-cost items that have low probability of failure is not justified.

The time required to receive the part from the vendor and the time required to replace the part on the unit also influence whether an item should be stocked. If the lead time for a critical part is a matter of weeks or months, or if a component must be specially built, stocking such items is advantageous.

Many plants have an electronics and mechanical shop whose highly trained staff can repair or rebuild components to meet original design specifications. The availability of this service can greatly reduce the need to maintain component parts or subassemblies. In these cases, one replacement can be stocked for installation during the period when repairs are being made. For example, many printed circuit boards can be repaired internally, which reduces the need to stock a complete line of electronic spare parts.

8.5 WORK ORDER SYSTEMS

A work order system is a valuable tool that allows the fabric filter coordinator to track unit performance over a period of time. Work order and computer tracking systems are generally designed to ensure that the work has been completed and that charges for labor and parts are correctly assigned for accounting and planning purposes. With minor changes in the work order form and in the computer programs, the work order also can permit continuous updating of failure-frequency records and can indicate whether the maintenance performed has been effective in preventing repeated failures. In general, the work order serves three basic functions:

1. It authorizes and defines the work to be performed.
2. It verifies that maintenance has been performed.
3. It permits the direct impact of cost and parts data to be entered into a central computerized data handling system.

To perform these functions effectively, the work order form must be specific, and the data fields must be large enough to handle detailed requests and to provide specific responses. In many computerized systems, the data entry cannot accommodate a narrative request and specific details are lost.

Most systems can accommodate simple repair jobs because they do not involve multiple repairs, staff requirements, or parts delays. Major repairs, however, become lost in the system as major events because they are subdivided into smaller jobs that the system can handle. Because of this constraint, a large repair project with many components (e.g., a cleaning system failure or control panel repair) that may have a common cause appears to be a number of unrelated events in the tracking system.

For diagnostic purposes, a subroutine in the work order system is necessary that links repairs, parts, and location of failure in an event-time profile. Further, the exact location of component failures must be clearly defined. In effect, it is more important to know the pattern of failure than the cost of the failure.

The goal of the work order system can be summarized in the following items:

- To provide systematic screening and authorization of requested work.
- To provide the necessary information for planning and coordination of future work.
- To provide cost information for future planning.
- To instruct management and craftsmen in the performance of repair work.
- To estimate manpower, time, and materials for completing the repair.
- To define the equipment that may need to be replaced, repaired, or redesigned (work order request for analysis of performance of components, special study, or consultation, etc.).

Repairs to the unit may be superficial or cosmetic in nature or they may be of an urgent nature and require emergency response to prevent damage or failure. In a major facility, numerous work order requests may be submitted as a result of daily inspections or operator analysis. Completing the jobs in a reasonable time requires scheduling the staff and ordering and receiving parts in an organized manner.

For effective implementation of the work order system, the request must be assigned a level of priority as to completion time. These priority assignments must take into consideration plant and personnel safety, the potential effect on emissions, potential damage to the equipment, maintenance personnel availability, parts availability, and boiler or process availability. Obviously, all jobs cannot be assigned the highest priority. Careful assignment of priority is the most critical part of the work order system, and the assignment must be made as quickly as possible after requests are received. An example of a five-level priority system is provided in Figure 8-4.

If a work order request is too detailed, it will require extensive time to complete. Also, a very complex form leads to superficial entries and erroneous data. The form should concentrate on the key elements required to document the need for repair, the response to the need (e.g., repairs completed), parts used, and manpower expended. Although a multipage form is not recommended, such a form may be used for certain purposes. For example, the first page can be a narrative describing the nature of the problem or repair required and the response to the need. It is very important that the maintenance staff indicate the cause of the failure and possible changes that would prevent recurrence. It is not adequate simply to make a repair to malfunctioning shaker cleaning system controls and respond that "the repairs have been made." Unless a detailed analysis is made of the reason for the failure, the event may be repeated several times. Treating the symptom (making the repair; replacing bags, solenoid valves, etc.) is not sufficient; the cause of the failure must be treated.

In summary, the following is a list of how the key areas of a work order request are addressed:[1]

1. Date - The date is the day the problem was identified or the job was assigned if it originated in the planning, environmental, or engineering sections.
2. Approved by - This indicates who authorized the work to be completed, that the request has been entered into the system, and that it has been assigned a priority and schedule for response. The

WORKORDER PRIORITY SYSTEM

PRIORITY	ACTION
1	Emergency Repair
2	Urgent repair to be completed during the day
3,4	Work which may be delayed and completed in the future
5	Work which may be delayed until a scheduled outage

Figure 8-4. Example of five-level priority system.
(Courtesy of PEI Associates, Inc.)

maintenance supervisor or fabric filter coordinator may approve the request, depending on the staff and the size of the facility. When emergency repairs are required, the work order may be completed after the fact, and approval is not required.

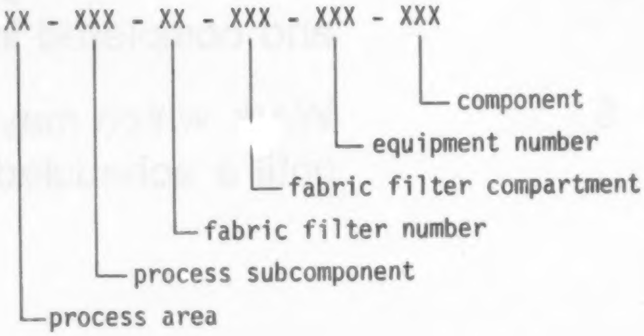
3. Priority - Priority is assigned according to job urgency on a scale of 1 to 5.

4. Work order number - The work order request number is the tracking control number necessary to retrieve the information from the computer data system.

5. Continuing or related work order numbers - If the job request is a continuation of previous requests or represents a continuing problem area, the related number should be entered.

6. Equipment number - All major equipment in a fabric filter should be assigned an identifying number that associates the repair with the equipment. The numbering system can include process area, major process component, fabric filter number, fabric filter compartment, equipment number, and component. This numeric identification can be established by using a field of grouped numbers. For example, the following could be used:

ID number



If the facility only has one fabric filter and one process, the first five numbers (two groups) may not be required, and the entry is thus simplified. The purpose of the ID system is to enable analysis of the number of events and cost of repair in preselected areas of the fabric filter. The fineness or detail of the equipment ID definition will specify the detail available in later analyses.

7. Description of work - The request for repair is usually a narrative describing the nature of the failure, the part to be replaced, or the work to be completed. The description must be detailed but

brief because the number of characters that can be entered into the computerized data system is limited. Additional pages of lengthy instruction regarding procedures may be attached to the request (not for computer entry).

8. Estimated labor - Assignment of personnel and scheduling of outages of certain equipment require the inclusion of an estimate of man-hours, the number of in-house staff needed, and whether outside labor is needed. The more complex jobs may be broken down into steps, with different personnel and crafts assigned specific responsibilities. Manpower and procedures in the request should be consistent with procedures and policies established in the O&M manual.

9. Material requirements - In many jobs, maintenance crews will remove components before a detailed analysis of the needed materials can be completed; this can extend an outage while components or parts are ordered and received from vendors or retrieved from the spare parts inventory. Generally, the cause of the failure should be identified at the time the work order request is filled, and specific materials needs should be identified before any removal effort begins. If the job supervisor knows in advance what materials are to be replaced, expended, or removed, efficiency is increased and outage time reduced. Also, if parts are not available, orders may be placed and the parts received prior to the outage. Material requirements are not limited to parts; they also include tools, safety equipment, etc.

10. Action taken - This section of the request is the most important part of the computerized tracking system. A narrative description of the repair conducted should be provided in response to the work order request. The data must be accurate and clearly respond to the work order request.

11. Materials replaced - An itemized list of components replaced should be provided for tracking purposes. If the component has a preselected ID number (spare parts inventory number), this number should be included.

Actual man-hours expended in the repair can be indicated by work order number on separate time cards and/or job control cards by craft and personnel number.

Copies of work orders for the fabric filter should be retained for future reference. The fabric filter coordinator should review these work orders routinely and make design changes or equipment changes as required to reduce failure or downtime. An equipment log also should be maintained, and the work should be summarized and dated to provide a history of maintenance on the unit.

Figure 8-5 shows a simplified work order request form. Changes in design for individual applications and equipment must be made to meet site-specific requirements.

8.6 COMPUTERIZED TRACKING

8.6.1 Work Orders

If the work completed and parts used in the fabric filter have been entered in the computerized work order system with sufficient detail, maintenance and management personnel can evaluate the effectiveness of fabric filter maintenance.

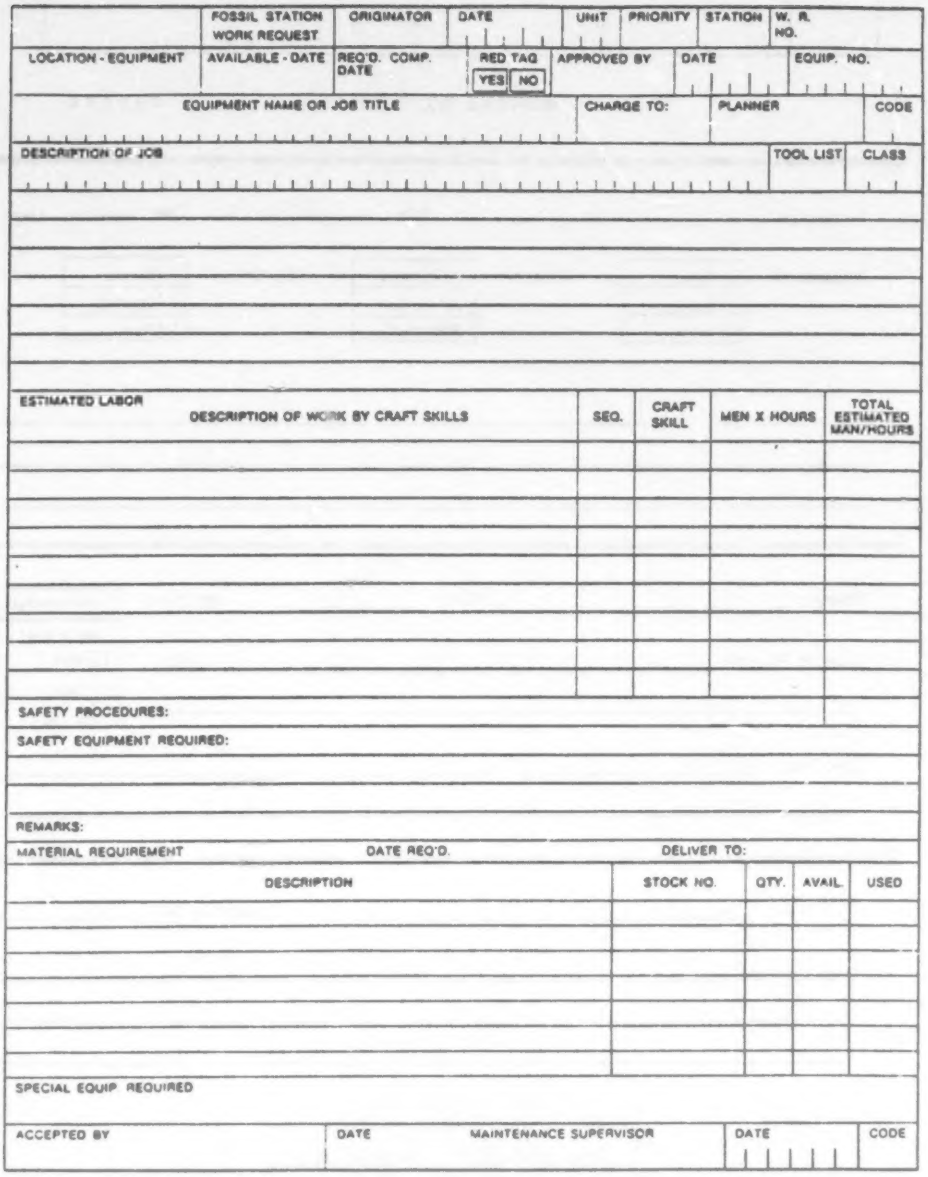
Preventive maintenance (PM) man-hours versus repair man-hours also can be compared to evaluate the effectiveness of the current PM program. The level of detail may allow tracking of the impact of PM on particular subgroups (e.g., shakers, hoppers) as changes are made in PM procedures. The effectiveness of the PM program may be further evaluated by the required number of emergency repairs versus scheduled repairs over a period of time (i.e., priority 2 versus priority 5, etc.).

It should be emphasized that the purpose of the computerized tracking system is not to satisfy the needs of the accountants or programmers or to state that the plant has such a system. Rather, the purpose of a computerized tracking system is to provide the necessary information to analyze fabric filter maintenance practices and to reduce component failures and excess emissions. The maintenance staff and fabric filter coordinator must clearly define the kind of data required, the level of detail, and the type of analysis required prior to the preparation of the data-handling and report-writing software. Examples of output may be man-hours by department, man-hours by equipment ID, number of repairs, number of events, number of parts, and frequency of events.

8.6.2 Fabric Filter Operating Parameters

In addition to tracking work orders, the computer can be used to develop correlations between process and fabric filter parameters and observed

WORK ORDER



	FOSSIL STATION WORK REQUEST	ORIGINATOR	DATE	UNIT	PRIORITY	STATION	W. R. NO.

LOCATION - EQUIPMENT	AVAILABLE - DATE	REQ'D. COMP. DATE	RED TAG ☐ YES ☐ NO	APPROVED BY	DATE	EQUIP. NO.

EQUIPMENT NAME OR JOB TITLE	CHARGE TO:	PLANNER	CODE

DESCRIPTION OF JOB	TOOL LIST	CLASS

ESTIMATED LABOR DESCRIPTION OF WORK BY CRAFT SKILLS	SEQ.	CRAFT SKILL	MEN X HOURS	TOTAL ESTIMATED MAN/HOURS

SAFETY PROCEDURES:

SAFETY EQUIPMENT REQUIRED:

REMARKS:

MATERIAL REQUIREMENT DATE REQ'D. DELIVER TO:

DESCRIPTION	STOCK NO.	QTY.	AVAIL.	USED

SPECIAL EQUIP REQUIRED

ACCEPTED BY	DATE	MAINTENANCE SUPERVISOR	DATE	CODE

Figure 8-5a. Example of work order form.[1]
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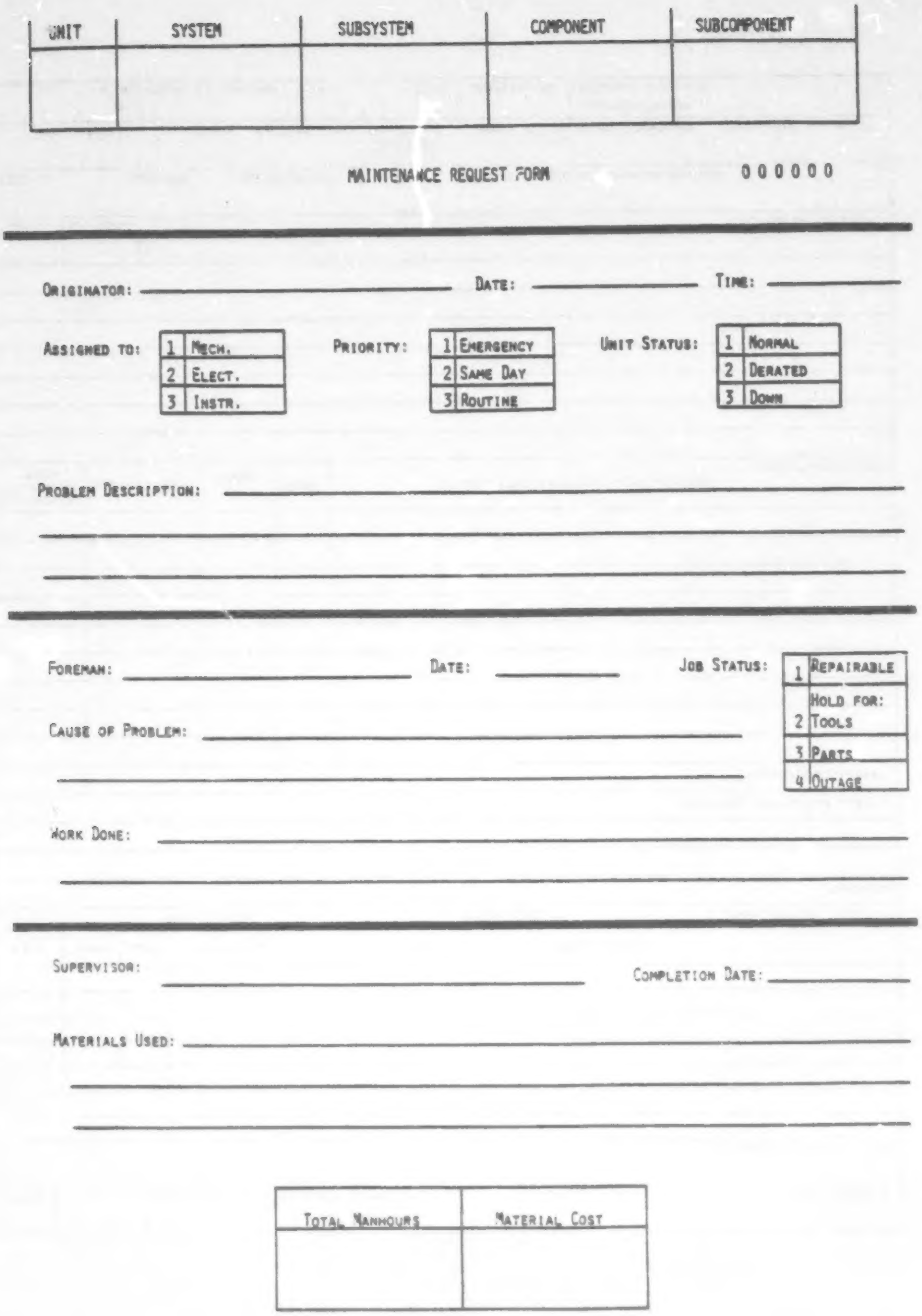

UNIT	SYSTEM	SUBSYSTEM	COMPONENT	SUBCOMPONENT

MAINTENANCE REQUEST FORM 000000

ORIGINATOR: ____ DATE: ____ TIME: ____

ASSIGNED TO:

1	MECH.
2	ELECT.
3	INSTR.

PRIORITY:

1	EMERGENCY
2	SAME DAY
3	ROUTINE

UNIT STATUS:

1	NORMAL
2	DERATED
3	DOWN

PROBLEM DESCRIPTION: ____

FOREMAN: ____ DATE: ____

JOB STATUS:

1	REPAIRABLE
2	HOLD FOR: TOOLS
3	PARTS
4	OUTAGE

CAUSE OF PROBLEM: ____

WORK DONE: ____

SUPERVISOR: ____ COMPLETION DATE: ____

MATERIALS USED: ____

TOTAL MANHOURS	MATERIAL COST

Figure 8-5b. Example of work order form.[2]
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emission profiles. Depending on the type of cycles expected in process operation, the data may be continuously input into the system or it may be entered from operating logs or daily inspection reports once or twice a week.

The key data for tracking performance are pressure differentials, opacity (i.e., 6-minute averages), boiler load (or associated parameter proportional to gas flow volume), flue gas temperature, and fuel quality data (i.e., fuel source, ash, fineness, etc.).

8.7 PROCEDURES FOR HANDLING MALFUNCTION

Many malfunctions are of an emergency nature and require prompt action by maintenance staff to reduce emissions or prevent damage to the unit. On some units, predictable but unpreventable malfunctions can be identified; such malfunctions include hopper pluggages, bag failure, and cleaning system failure. These problems, as well as corrective actions, are discussed in Sections 4.2 and 4.3.

An effective O&M program should include established written procedures to be followed when malfunctions occur. Having a predetermined plan of action reduces lost time, increases efficiency, and reduces excessive emissions. The procedures should contain the following basic elements: malfunction anticipated, effect of malfunction on emissions, effect of malfunction on equipment if allowed to continue, required operation-related action, and maintenance requirements or procedure.

REFERENCES FOR SECTION 8

1. Vuchetich, M. A., and R. J. Savoi. Electrostatic Precipitator Training Program and Operation and Maintenance Manual Development at Consumers Power Company. In: Proceedings Conference on Electrostatic Precipitator Technology For Coal-Fired Power Plants. EPRI CS-2908 - April 1983.

2. Rose, W. O. Fossil Maintenance Documentation at Duke Power Company. In: Proceedings Conference on Electrostatic Precipitator Technology For Coal-Fired Power Plants. EPRI CS-2908 - April 1983.

APPENDIX A

EXAMPLES OF FABRIC FILTER O&M FORMS

Company ______________________

Type of inspection ______________________

Date ______________

Name ______________

Check	Good	Needs attn.
Serial No. ______________		
( ) Structural-bolts	( )	( )
( ) Ladder assembly	( )	( )
( ) Airlock	( )	( )
( ) Drive assembly		
A. Gear reducer	( )	( )
B. Drive shaft align	( )	( )
C. Coupler shaft	( )	( )
D. Bearings	( )	( )
E. Belts	( )	( )
F. Sheaves	( )	( )
G. Serial No. (motor) __________		
H. hp ________		
I. rpm ________		
J. Sheave size ________		
( ) Transfer screw assy.	( )	( )
( ) Fan		
A. Serial No. ________		
B. Model No. ________		
C.		
D. Make ______________		
E. Sheaves	( )	( )
F. Sheave diameter	( )	( )
G. Shaft diameter	( )	( )
H. Series of belts __________		
I. Shaft diameter __________		
J. Make ______________		
( ) Water trap	( )	( )
( ) Air regulator	( )	( )
( ) Bin indicator	( )	( )
( ) Magnehelic	( )	( )
( ) Magnehelic tubing	( )	( )
( ) Baffle wear	( )	( )

Item	Check	Good	Needs attn.
15.	( ) Top door hold-down straps	( )	( )
16.	( ) Top door leaks	( )	( )
17.	( ) Manifold pipes anchored	( )	( )
18.	( ) Manifold pipes holes	( )	( )
19.	( ) Manifold pipes center over venturi	( )	( )
20.	( ) Venturi properly seated	( )	( )
21.	( ) Cages properly installed	( )	( )
22.	( ) Bag clamps	( )	( )
23.	( ) Bags-Visolite^{R}	( )	( )
24.	( ) Bags-general appear.	( )	( )
25.	( ) Service module		
	A. Wire connections terminal box	( )	( )
	B. Wire connections		
	C. Diaphragm valves-leaks	( )	( )
	D. Solenoid valves operating	( )	( )
	E. Hoses and clamps	( )	( )
	F. Air pressure leak psi	( )	( )
26.	( ) Pulse control panel	( )	( )
27.	( ) Control panel	( )	( )
28.	( ) Dialatrol	( )	( )
29.	( ) Thermocouple	( )	( )
30.	( ) Thermocouple wiring	( )	( )

Item	Check	Good	Needs attn.
31.	( ) Timer settings		
	A. Duration ________		
	B. Interval ________		
32.	( ) Delta P		
	A. Low ________		
	B. High ________		
	C. Average ________		
33.	( ) psi at header		
	A. Low ________		
	B. High ________		
34.	Average temperature in baghouse ________		
35.	Visual stack emission		
	Clean ______		
	Dirty ______		
36.	( ) Paint		
	A. Interior	( )	( )
	B. Exterior	( )	( )

NOTES

____

____

____

____

____

____

Example fabric filter inspection report form.

Source: Reigel, S. A. Fabric Filtration Systems, Design, Operation, and Maintenance.

Source I.D. No. ____________________ SIC ______________________________

Inspector(s) ______________________ Date ______________________________

Inspection Announced? ____

A. GENERAL PLANT DATA FROM AGENCY FILE

1. Source name, address, and phone number ____
____
____
____

2. Type of process ____
____

3. Allowable emission rate and opacity ______________________________
____
____
____

4. Date baghouse installation approved ______________________________
____
____

5. Prior complaints or episodes of excess emissions ________________
____
____
____

6. Last inspection date ____

7. Purpose of inspection ____
____

B. GENERAL OBSERVATIONS PRIOR TO ACTUAL INSPECTION

1. Weather conditions ____

2. Visible emissions ____
____

Fabric filter inspection report form.

3. Is inspector a certified smoke reader? Yes ___ No ___ If yes, give certification date ______________________________
(Attach copy of Method 9, if performed)

C. PROCESS INFORMATION

1. Confidential? Yes ___ No ___

2. Person contacted at plant and title ______________________________
____

3. Product(s) produced ______________________________
____

4. Production rate(s) ______________________________
____

5. Raw materials used ______________________________
____
____

6. Portion of process controlled by baghouse ______________________
____
____
____

7. Average uncontrolled emission rate or concentration (indicate weather obtained from stack test, mass balance, AP-42 emission factor, other, etc.) ______________________________
____
____

8. Date of last stack test and average emission rate obtained _______
____
____

9. Is cleaned effluent recirculated back into plant? Yes ___ No ___

D. DUST CHARACTERISTICS (PRIOR TO CONTROL)

1. Is material toxic or otherwise hazardous or does it require special handling: Yes ___ No ___ Describe ______________________

Fabric filter inspection report form. (continued)

2. Moisture content or other gaseous constituents ____________________
____

3. Abrasiveness or other properties ____________________
____

4. Particle size data - indicate how measured ____________________
____
____

E. COLLECTION SYSTEM(S)

1. Baghouse	No. 1	No. 2	No. 3
a. Manufacturer			
b. Type or trade name			
c. Model No.			
d. No. of compartments			
e. Bags/compartment			
f. Bag l x d			
g. Total Cloth Area			

2. Fan	No. 1	No. 2	No. 3
a. Manufacturer			
b. Model No.			
c. Blade type			
d. Belt or direct drive			
e. Power rating			
f. Positive or negative pressure			

3. Fabric	No. 1	No. 2	No. 3
a. Manufacturer			
b. Material			
c. Woven or felted			
d. Weave			
e. Weight			
f. Permeability			

Fabric filter inspection report form. (continued)

	No. 1	No. 2	No. 3
g. Operating temp. range			
h. Surface treatment			
i. Coating upon startup			
j. Guaranteed life			
k. Actual life			

4. Cleaning System	No. 1	No. 2	No. 3
a. Method			
b. Frequency			
c. Actuated by			
d. Anticollapse rings			
e. Wire mesh cages			

F. DUST HANDLING SYSTEM(S)

1. Do baghouse hoppers have:
    a. Heaters
    b. Insulation
    c. Level indicators
    d. Vibrators
2. Type of dust transport system
3. Fate of collected material

G. INSTRUMENTATION

Do system monitors record any of the following:

1. Process start-up/shutdown

Fabric filter inspection report form. (continued)

2. System flow or velocity
3. Fan motor amps
4. Temperature (recording?)
5. Pressure
6. Opacity
7. Outlet emissions
8. Compartments off-line
9. Compartments being cleaned
10. Compartments in operation
11. Other

H. OPERATING PARAMETERS - DESIGN AND ACTUAL

Design **Actual**

1. Flow rate
2. Pressure drop,
flange-to-flange
measurement location
3. A/C, gross
4. A/C, net
(2 comp. down)
5. Temperature
6. Efficiency

Fabric filter inspection report form. (continued)

7. Emission rate ______________________________

____

____

8. Opacity ______________________________

____

____

I. OPERATING EXPERIENCE/MAINTENANCE ASPECTS

1. Percent of time baghouse fully operational when process is in operation ______________________________

____

2. Has a detailed maintenance schedule been instituted? __________

____

3. Is maintenance scheduled as recommended by baghouse manufacturer or by plant? ______________________________

____

____

4. Are maintenance records available for inspection? __________

____

5. How long are records kept on file? ______________

____

6. Which of the following problem areas have led to periods of excess emissions or caused the process to be shut down?

Problem Area	Duration	Frequency
a. Insufficient dust pickup and/or transport (fugitive emissions)		
b. Duct abrasion or corrosion		
c. Temperature excursions, high or low		
d. Moisture		
e. Fan abrasion, vibration, etc.		
f. Gross bag failure		
g. Inadequate bag tension		
h. Bag chafing or abrasion		

Fabric filter inspection report form. (continued)

	Problem Area	Duration	Frequency
i.	Pressure loss		
j.	Compartment isolation dampers		
k.	Cleaning mechanism		
l.	Visible emissions		
m.	Plugged hoppers		
n.	Hopper fires		
o.	Dust discharge system		

J. CONCLUSIONS/RECOMMENDATIONS

1. Compliance status ____________________

2. Need for further action ____________________

3. Corrective actions to be taken ____________________

4. Time required to rectify problems ____________________

5. Special waivers or review of compliance criteria required ____________________

6. Need for follow-up inspection ____________________

7. Inspector's signature ____________________
   date ____________________
   approved by ____________________
   title ____________________

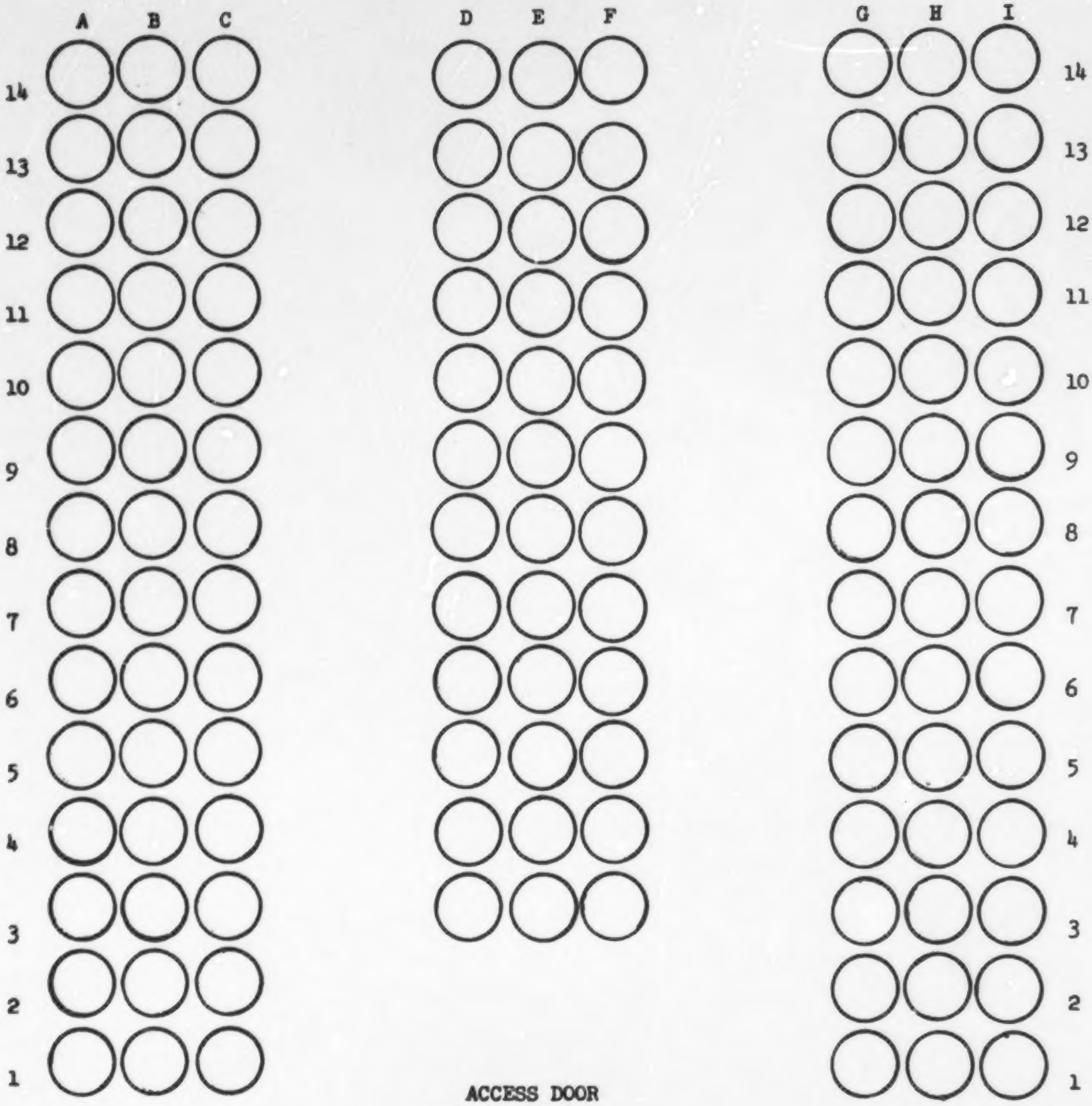
Fabric filter inspection report form. (continued)

K. OTHER NOTES, COMMENTS, SKETCHES (ATTACH ADDITIONAL PAGES, IF NECESSARY)

Schematic drawings showing locations of process and dust control equipment should be prepared, particularly so, where verbal descriptions may lead to misunderstandings.

Fabric filter inspection report form.

BAG FAILURE LOCATION RECORD



MODULE NO. ___________

DATE_________________

REPLACE - R	CAP-OFF - C
PATCH - P	RETENSION - T

APPENDIX B

OPERATION AND MAINTENANCE OF UTILITY FABRIC FILTERS

INTRODUCTION

Interest in the application of baghouse technology to electric utility boilers began in the late 1960's. The advent of the Clean Air Act of 1970 gave impetus to the investigation of this technology, which continued through the 1970's. The Clean Air Act also precipitated the particulate emissions limitations of the 1971 New Source Performance Standards (NSPS), which were revised in 1979 to include even more stringent particulate emission limitations for utility coal-fired boilers.

Prior to the 1970's, utilities primarily used electrostatic precipitators (ESP's) for particulate control. These devices were relatively economical and performed well in terms of particulate removal efficiency with the high-sulfur (2 to 5 percent) Midwestern and Easter coals common at the time. The low-sulfur western coals that were used in the western part of the country, however, produced an ash that was more difficult for an ESP to collect. As a result, ESP's were less attractive for these applications both in terms of cost and removal performance. Also, when the more stringent regulatory standards of the 1970's put strict limitations on SO_2 emissions, the industry began shifting from high-sulfur to low-sulfur coals (less than 1 percent) to reduce SO_2 emissions. Although the 1971 NSPS regulations for SO_2 emissions could be met with low-sulfur "compliance coal," various utilities began to use SO_2 scrubbers when the use of low-sulfur coal was impractical or where, for example, state SO_2 emission standards were more stringent than the applicable Federal standards (NSPS).

While these events were taking place, fabric filter technology continued to evolve. The 1979 NSPS revisions eliminated the advantage of using low-sulfur coal (at least in the Eastern and Midwestern parts of the country) when it became clear that all coal-fired units would be required to employ some type of flue gas desulfurization (FGD) system regardless of the coal sulfur content. In addition, these new standards further reduced allowable particulate emissions, which made ESP's even less practical for low-sulfur coal applications. About this time, a special class of FGD system called a spray dryer became available for use with low-sulfur coal. In these systems, fabric filters are normally used in conjunction with the spray dryer equipment. By combining SO_2 and particulate collection, this system configuration reduced the need for separate SO_2 removal equipment (which can account for as much as 25 percent of the total plant cost). The first full-scale low-sulfur application of this type was the 440-MW Coyote power station owned and operated by Otter Tail Power, which began operations in April 1980.

The traditional barrier to the use of fabric filters in the electric utility industry was the unavailability of a bag fabric durable enough to withstand elevated operating temperatures; to resist chemical attack; and to maintain dimensional stability, tensile strength, and flex strength.[1] When suitably finished, woven fiberglass fabrics became available in the early 1960's, the use of fabric filters in the utility industry became more feasible.

In 1961, Pennsylvania Power & Light Co. began operations at a pilot fabric filter installation.[2] Although the results were good, the utility opted for ESP's at the full-scale facility. In 1964, Public Service Electric & Gas Co. also tested and discarded the fabric filter concept.

Installation of the first full-scale utility fabric filter in the United States was in 1965--at the 320-MW oil/gas-fired Alamitos station owned and operated by Southern California Edison Co. A fabric filter was installed at this facility to eliminate both a visible plume attributed to fine particles and a sulfuric acid fume resulting from the combustion of residual fuel oil with a 1.7 percent sulfur content. In this installation, various alkaline additives (e.g., dolomite and limestone) were injected upstream of the fabric filter to react with the SO_3 in the flue gas. This material was then collected in the fabric filter system. After 5 years of operation, the system was shut down permanently when the utility was unable to obtain a variance to continue burning high-sulfur oil.

The first full-scale application of a fabric filter at a coal-fired utility boiler occurred in February 1973.[1] The site of this installation was the four-boiler, 87.5-MW Sunbury station of Pennsylvania Power & Light Co. In the 10 years following this initial application, utility commitments to baghouse technology grew rapidly. By the first quarter of 1984, more than 110 baghouses were either in operation, under construction, or in the design phase; the total power generating capacity involved was more than 20,000 MW.[1]

The growth in fabric filter usage is illustrated in Figure B-1, which plots the cumulative installations (in terms of associated electrical generating capacities) by year of startup. The actual units represented by these capacity figures are shown in Table B-1. To put this information in proper perspective, Figure B-2 presents a rescaled version of the Figure B-1 plot superimposed on a plot of the U.S. utility coal-fired power generating capacity installed by year.

When compared with the population of coal-fired units as a whole, the impact of fabric filters is small; however, the number of projected coal-fired boilers that will be equipped with fabric filters is expected to increase. Also, a significant number of existing plants are expected to convert to the use of fabric filter technology for particulate emission control in the years to come.

TYPES OF FABRIC FILTERS IN USE

Fabric filters are normally classified by fabric cleaning method. The three primary cleaning methods are shake-deflate, reverse-gas, and pulse-jet. Only the first two are widely used in utility applications, and the reverse-gas method is by far the most prevalent*. Of the 72 utility boilers equipped with fabric filters as of June 1981, 9 were of the shake-deflate design, 2 were of the pulse-jet design, and all the rest were of the reverse-gas design.

Pulse-jet fabric filters work well for the shorter, small-diameter bags found on smaller-scale industrial applications. Because utility systems

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*Recent research and economic studies now show that a shake/deflate fabric filter with an air-to-cloth ratio of 2.7 acfm/ft² offers a lower total cost than reverse-gas units with comparable or lower air-to-cloth ratios.

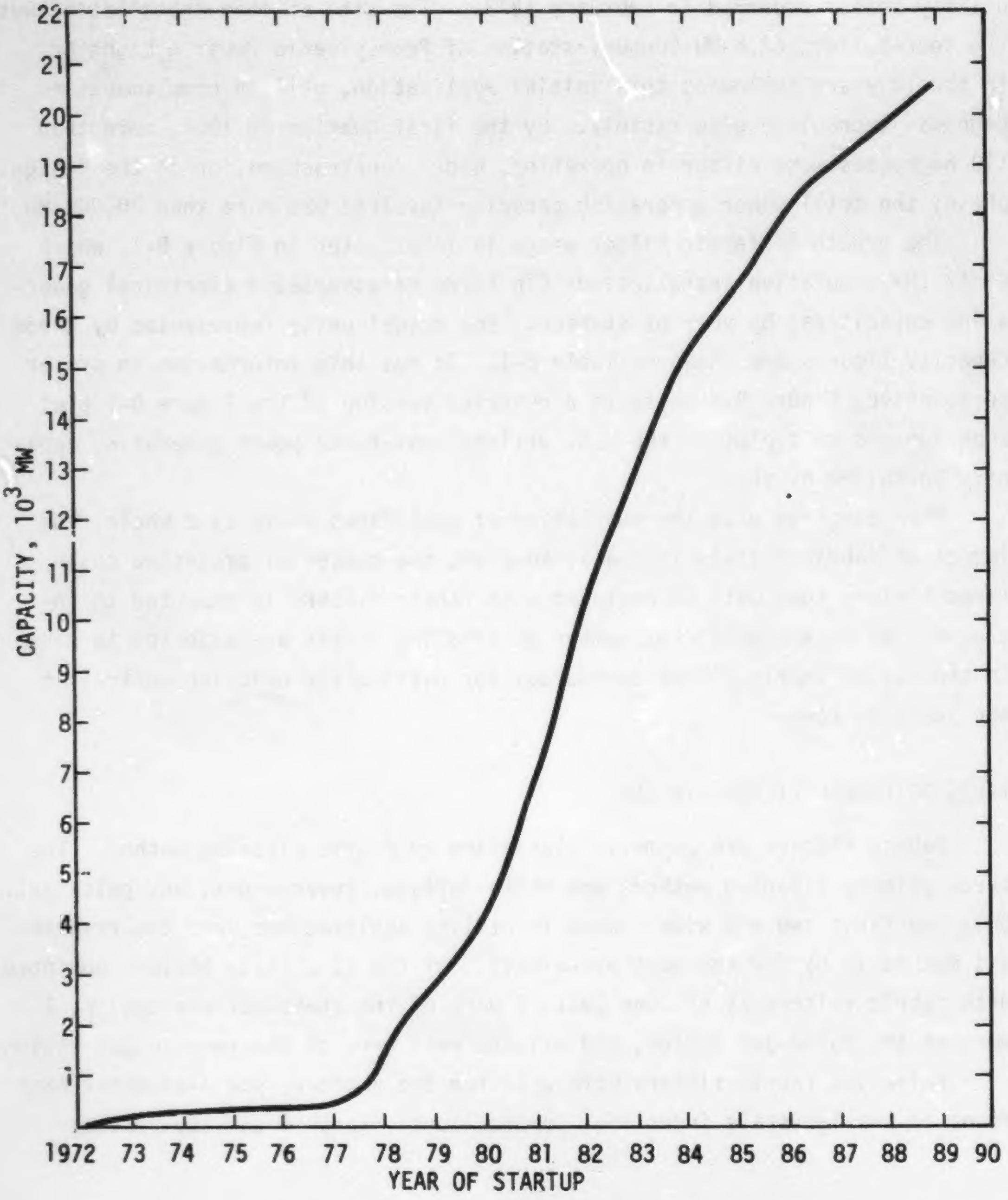

Figure B-1. Cumulative electrical generating capacity controlled by fabric filters, by year of startup.

8

TABLE B-1. FABRIC FILTERS IN OPERATION, UNDER CONSTRUCTION, OR IN THE DESIGN PHASE IN THE U.S. ELECTRIC UTILITY INDUSTRY

UTILITY	STATION NAME	RATING MW	BOILER TYPE [a]	A/C RATIO (acfm/ft^2)[b]	CLEANING METHOD [c]	DATE COMMISSIONED
Arizona Public Service	Four Corners	2x800	PC	2.1	RG	1982
Atlanta City Electric	Deepwater	2x23	PC	--	RG	1982
Atlanta City Electric	Deepwater	40	PC	2.13	RG	1983
Baltimore Gas & Electric	Crane	2x197	C	1.96	RG	1983
Basin Electric Power Coop.	Antelope Valley	2x440	PC	2.36	RG	1983/84
Cajun Electric Coop.	Oxbow	540	PC	--	RG	1986
City of Colorado Springs	R. D. Nixon	200	PC	2.03	RG	1980
City of Colorado Springs	Martin Drake	85	PC	1.85	RG	1978
City of Columbia Water and Light	Columbia	16.5	S	2.75	RG	1979
City of Columbia Water and Light	Columbia	22	S	2.75	RG	1979
City of Duluth	Duluth	3x--	PC	2.76	RG	1980
Colorado - Ute Electric Assn., Inc.	Bullock	2x6.25	PC	1.96	RG	1979
Colorado - Ute Electric Assn., Inc.	Nucla	3x13	S	3.35	SD	1973/74
Colorado - Ute Electric Assn., Inc.	Craig	440	PC	2.06	RG	1983
Cooperative Power Association	Coal Creek	91	So	3.5	SD	1979
Cooperative Power Association	Coal Creek	92	So	3.5	SD	1979
Crisp County Power Commission	Plant Crisp	12.5	PC	1.5	RG	1975
Dayton Power & Light Company	Longworth	Steam	S	6.86	PJ	1978
Desert Generation and Transmission	Bonanza	400	PC	1.96	RG	1984
Fremont Dept. of Utilities	Lon D. Wright	22	PC	2.6	RG	1979
Fremont Dept. of Utilities	Lon D. Wright	16.5	PC	2.6	RG	1979
Golden Valley Electric Assn., Inc.	Healy	22	PC	1.82	RG	1979
Houston Lighting & Power Company	W. A. Parish	551	PC	1.8	RG	1982
Independence Power & Light Dept.	Missouri City	2x22	PC	2.24	RG	1982
Intermountain Power	Intermountain	4x820	PC	2.0	RG	1986-89
Kansas City Board of Public Utilities	Kaw	2x44	PC	2.02	RG	1979
Kansas City Board of Public Utilities	Kaw	68	PC	2.0	RG	1980
Marquette Board of Light and Power	Shiras	15	S	1.75	RG	1979
Marquette Board of Light and Power	Shiras	22	S	1.75	RG	1980
Marquette Board of Light and Power	Shiras	44	PC	1.98	RG	1983
Marshall Municipal Utilities	Marshall	6	PC	2.72	RG	1980
Marshall Municipal Utilities	Marshall	16.5	PC	2.47	RG	1980
Minnesota Power and Light Company	Clay Boswell	2x69	PC	2.26	RG	1979
Nebraska Public Power District	Kramer	3x23	PC	2.1	RG	1977
Nebraska Public Power District	Kramer	36	PC	1.91	RG	1977
Nevada Power Company	Reid Gardner	250	PC	1.97	RG	1983
Nevada Power Company	Warner Valley	2x250	PC	1.97	RG	1985
Northern States Power Company	Riverside	2x110	PC	2.25	RG	1981
Ohio Edison	W. H. Sammis	4x180	PC	2.31	RG	1982/83
Otter Tail Power Company	Coyote	410	C	2.5	SD	1981
Pennsylvania Power & Light Company	Sunbury	2x87.5	PC	2.05	RG	1973
Pennsylvania Power & Light Company	Holtwood	79	PC	2.42	SD	1975
Pennsylvania Power & Light Company	Holtwood	79	PC	2.0	RG	1981
Pennsylvania Power & Light Company	Brunner Island	350	PC	2.01	RG	1980
Philadephia Electric Company	Cromby	15	PC	5.12	PJ	1980
Piqua Municiple Power System	Piqua	3x44	S	2.5	RG	1980
Plains Electric Gen. Transmission Coop.	Escalante	210	PC	2.1	RG	1983
Platte River Power Authority	Rawhide	250	PC	1.77	RG	1985
Public Service Co. of Colorado	Arapahoe	44	PC	2.16	RG	1979
Public Service Co. of Colorado	Cameo	22	PC	2.41	RG	1979
Public Service Co. of Colorado	Cameo	44	PC	2.31	RG	1978
Public Service Co. of Colorado	Cherokee	110	PC	2.06	RG	1980
Public Service Co. of Colorado	Cherokee	150	PC	2.1	RG	1980
Rochester Public Utility Dept.	Rochester	2x--	S	2.43	RG	1979
Sierra Pacific Power Company	North Valmy	250	PC	2.7	RG	1981
Sierra Pacific Power Company	North Valmy	250	PC	--	RG	1984
Southern Colorado Power Div.	Clark	16.5	S	1.9	RG	1978
Southern Colorado Power Div.	Clark	22	S	2.08	RG	1978
Southwestern Public Service Company	Ray Tolk	2x500	PC	2.1	RG	1982/84
Southwestern Public Service Company	Harrington	350	PC	3.4	SD	1978
Southwestern Public Service Company	Harrington	350	PC	3.0	SD	1980
Southwestern Public Service Company	Celanese (Cogen.)	2x30	PC	2.06	RG	1979
Sunflower Electric Coop.	Holcomb	280	PC	1.81	RG	1983
Tennessee Valley Authority	Shawnee	10x175	PC	2.2	RG	1981
Texas Utilities Company	Monticello	2x575	PC	2.9	SD	1978/79
Tuscon Electric Company	Springerville	2x350	PC	1.91	RG	1984
Tucson Electric Power	Irvington	2x50	PC	2.2	RG	1987
Tucson Electric Power	Irvington	90	PC	2.2	RG	1986
Tucson Electric Power	Irvington	100	PC	2.2	RG	1985
United Power Association	Elk River	2x11.5	S	2.45	RG	1978
United Power Association	Elk River	23	PC	2.45	RG	1978
United Power Association	Stanton	172	PC	2.23	RG	1982
Utah Power & Light	Hunter	2x400	PC	2.52	RG	1983/86

a. PC = Pulverized Coal
S = Stoker
C = Cyclone
So = Stoker w/oil

b. Based on one compartment out of service for cleaning, and one or two out of service, depending upon the particular case.

c. RG = Reverse-gas
SD = Shake/Deflate
PJ = Pulse Jet

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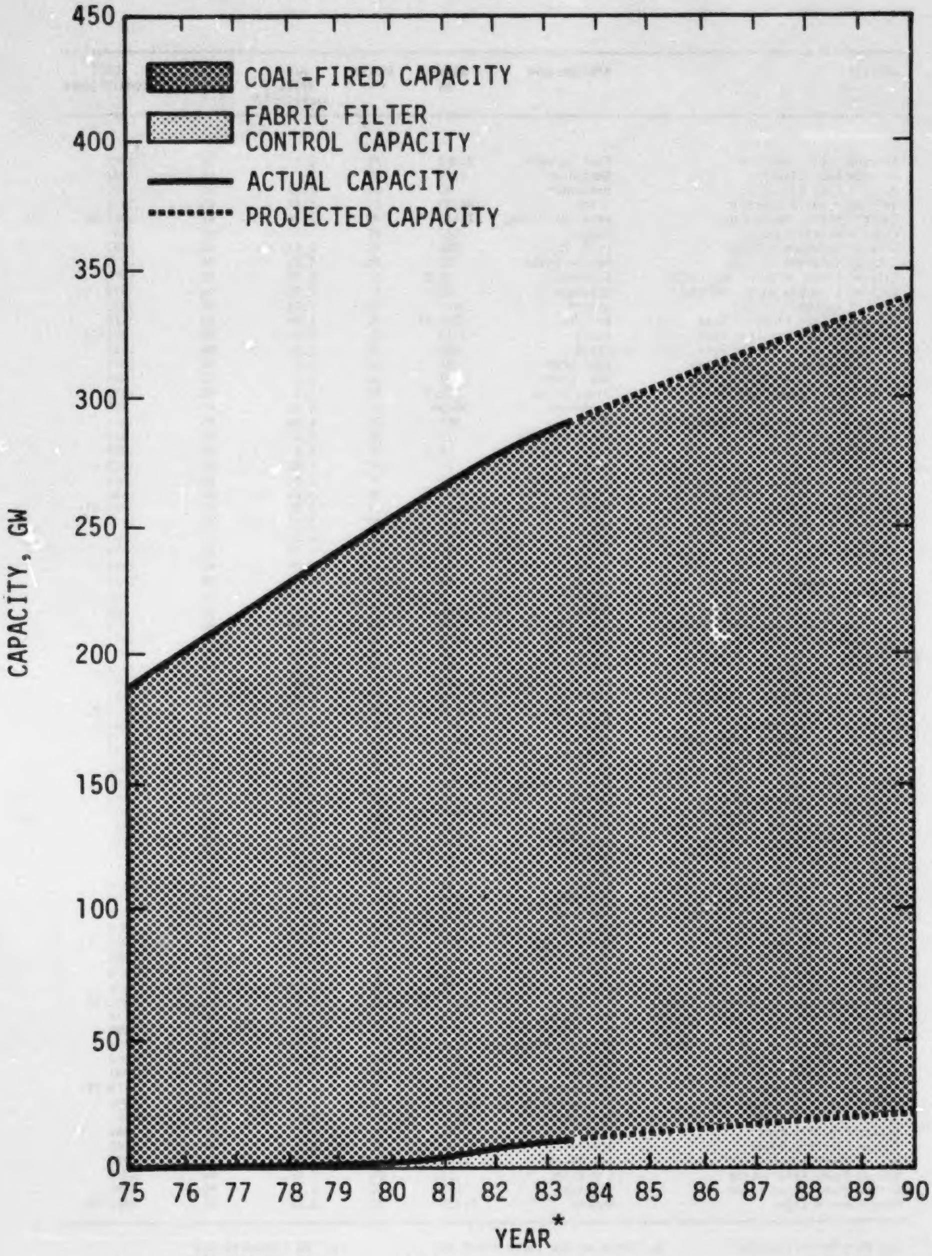

*YEAR-END TOTALS

Figure B-2. Actual and projected coal-fired generating capacity and capacity controlled by fabric filters, 1984.[1,3-7]

require much larger units (in terms of bag dimensions and other design aspects), the pulse-jet systems are less effective. Also, because of their dewaterability in high-temperature, potentially acid environments, coated fiberglass bags are generally used in utility applications. Since the more-brittle fiberglass material tends to wear out rapidly when flexed, it is not suitable for pulse-jet units.

Fabric filters used in utility applications, although similar in basic design, differ significantly from those used in typical industrial applications. Utility fabric filters may be 10 to 100 or more times larger than industrial fabric filters. Because of their larger size and stricter emission guidelines imposed upon these boilers (even at startup and shutdown), fabric filters become critical to the operation of the power plant. Therefore, more attention is directed toward such factors as operation and maintenance, energy efficiency, bag life, and preventative maintenance strategies. Other constraints also affect the design and operation of fabric filters for utility applications. For example, the temperature of flue gas from utility boilers is significantly higher than that encountered in many industrial applications, and the abrasive qualities of the fly ash also must be considered. The flue gas also contains significant moisture and acid constituents that require high temperatures (above 250°F) to be maintained to preclude acid dewpoint problems and moisture condensation on the bags. If high temperatures are not maintained, corrosion, bag fabric decay, and bag blinding can result.

In an effort to maintain the temperatures of the flue gas to the fabric filters, utilities have installed flange-to-flange insulation. Even with this insulation, localized corrosion may occur at any heat sinks where supports and ground-mounted structural beams are welded to the fabric filter framework. Precautions also must be taken in the "downcomer" sections to the hoppers. Corrosion can occur on the walls, and the ash may agglomerate in the hopper as the lower surface temperatures cause condensation. Some low-sulfur Western coals yield alkaline ashes that tend to "set up" when wetted, which further complicates the problem of ash removal. Care also must be taken to prevent inleakage of ambient air in the ash removal system, as this too reduces the flue gas temperature.

Because fly ash is abrasive, some design feature must be implemented, particularly at the gas inlet, to minimize the initial impact of the inlet gas stream on the bag fabric. No standard design is available to ensure adequate flow distribution of the flue gas (and therefore the fly ash) through the fabric filter. Some installations have no means of distribution other than the wedge-shaped inlet manifold; others have baffles, turning vanes, or a combination of the two.

In some instances, louvered dampers or butterfly valves are used, but poppet valves at the inlet and outlet of the compartments are most commonly used for flow control. There may be no real advantage to using poppet valves at the fabric filter inlet; in fact, there may be a pressure drop penalty. At the outlet, however, poppet valves prove superior to louver and butterfly dampers. Poppet valves seal very well. A two-valve design has a lower pressure drop penalty, because two paths offer less resistance for gas passage. Using a pair of valves (one large and one much smaller) has the same advantages as multiple gas paths, but also has the added advantage of reducing bag stresses during cleaning cycles. Bag reinflation is often accompanied by a loud "pop" as the flue gas rushes in to fill the void. This damages the fabric (particularly fiberglass) over a period of time. When the fabric filter design includes a small (pilot) poppet valve, the reinflation flow can be started more gradually. The small valve opens first during bag inflation, and the larger valve opens later to complete the inflation. On reverse-gas cleaning applications, both economics and a desire to achieve a "gentle" reinflation dictate the number and size of poppet valves at the outlet. Either two equal diameter poppet values or one large and one small valve are commonly used.

Except at the sites of the two pulse-jet installations, woven fiberglass is the bag material most installations often use. The coatings vary, but most are Teflon (10 percent by weight). A survey taken in 1981 indicated that those plants not using Teflon (roughly 13 percent) were using a silicon-graphite coating or one of the recently introduced acid-resistant finishes. The woven bags are typically attached to the tube sheet by means of thimbles 8 to 12 inches in height. These thimbles are used to prevent erosion of the bag material due to fly ash particles entering the bags from the hopper.

As mentioned earlier, utility and industrial fabric filters differ in several ways. For example, gas volumetric flow rate in electric utility systems may be as high as 4×10^6 acfm as opposed to 100,000 acfm in typical industrial applications. Energy costs resulting from ductwork and dust cake resistance pressure drop are generally much greater for utilities. In addition, utilities do not benefit from a product recovery credit of the collected material as many industries do. High flue gas temperatures in utility applications limit the choices of bag fabrics. The volume, flow, temperature, composition, and particulate concentration of the flue gas entering the fabric filters in utility applications vary greatly with the boiler load, and the fly ash represents a wide and often unpredictable range of coal properties.

MONITORING

Utility applications typically incorporate more monitoring devices than industrial fabric filter systems do to track the operation of the system and its related equipment. Monitoring and alarm devices display and/or record the gas flows and pressure losses within the system, incidents involving compartment isolation, inlet and outlet temperatures of the system, operation and sequencing of the cleaning apparatus, particulate emissions exiting the stack, and bag failure (i.e., severe plugging or rupture). Outlet opacity monitors are typically installed to satisfy environmental regulations, but they are also useful in detecting problems before they become serious. For example, when bag rupture problems were encountered at the Harrington Station of Southwestern Public Service Co., workers were able to pinpoint failures in the specific compartment through the use of opacity meters.

The outlet opacity monitor should be observed during normal filtering operation and during compartment cleaning. A gradual increase in opacity during filtering indicates a worsening bag or compartment leak (assuming the monitor itself is performing properly). During cleaning, a very clean filter will show almost no change in opacity as compartments are removed, cleaned, and put back into service. A drop in opacity when a compartment is removed from service indicates that the compartment has a leak. The opacity will also normally increase immediately when that particular module is put back in service.

The opacity may also increase momentarily when a given compartment is removed because of the disturbance of an accumulation of ash in the other compartments resulting from the sudden increase in gas flow in these compartments due to the removal of a compartment.

Pressure gauges, level indicators, and gas flow and temperature monitors also provide data for early detection of problems. Thus, it is apparent that good monitoring systems, dedicated maintenance, and quality control in the fabrication and installation of bags lead to greatly improved service and substantial savings in labor and repair costs.

O&M PROBLEMS AND PRECAUTIONS

Fabric filters have performed well on utility boilers. Design removal efficiencies for all fabric filters range from 99.4 to 99.9 percent, and in many cases, actual efficiencies have exceeded the design efficiencies. Opacities are typically below 5 percent. Pressure drops range between 3 and 12 inches, with newer installations showing values at the lower end of the range.

Assuming proper fabric filter design and proper bag installation, the most critical concern is startup and shutdown. Several typical maintenance problems and precautions are introduced briefly here and illustrated later in this appendix by case histories.

Operational Factors

Operating factors of concern on fabric filter systems include the cleaning system, the bags themselves, the ash-removal system, and overall system integrity.

Operators must be careful not to clean the bags too frequently. When bags are cleaned too frequently, the overall average pressure drop is higher because the dust cake is not as heavy and is harder to remove. Also, frequent bag cleaning weakens the material and shortens bag life.

Operators must minimize the potential for problems associated with startup and shutdown. If at all possible, the fabric filter system should be heated thoroughly (e.g., by gas-firing the boiler or by some other means) before the sulfur-laden gas from coal firing is allowed to enter the collector. If the fabric filter applied to a coal-fired unit is cold at startup, moisture from the flue gas will condense on the bags and walls, and the SO_3 in the gas will combine with the moisture to form sulfuric acid, which may result in corrosion and fabric decay. Also, moisture may cause "blinding" of the fabric when residual fly ash and water seal the air passages in the fiber weave. During shutdowns and forced outages, fabric filters should be purged as thoroughly as possible to remove moisture and sulfur-laden gases as the collector cools.

Operators should observe the performance of the reverse-gas valve and compressor system to assure adequate bag cleaning during the cleaning cycle. Operators also must carefully observe the fabric filter monitoring equipment to detect bag failures as early as possible. A serious bag failure can cause damage to surrounding bags.

Maintenance Factors

During bag replacement, care must be taken to minimize the risk of damage to other bags as a result of snags and punctures with tools and equipment. As the utility industry has become more familiar with fabric filter technology, problems relating to improper maintenance procedures have diminished in number.

Maintenance personnel must be certain that bag tensioning devices are properly adjusted and in good condition. One of the primary causes of bag failure can be traced to improper bag tensioning. Bags also must be installed properly. Improper installation may cause the bag to rupture and/or become dislodged. When this occurs, other bags can also be damaged.

Fabric filters are well maintained at most utility applications. The changeout time for 12-inch-diameter, 36-foot-long fiberglass bags is 15 to 20 minutes (two men). In most fabric filters, insulation is placed between compartments. Some also have ventilation systems to cool the compartments quickly, which permits personnel to work comfortably and safely to replace bags in an isolated compartment while the rest of the fabric filter system is still in service.

CASE HISTORIES

The case histories that follow were selected from a population of approximately 84 operating fabric filter installations. Selection was based on the availability of O&M data and on each case's typicality of U.S. utility fabric filter installations. Larger installations (500 MW and greater), however, are not well represented because fabric filters have only recently been applied on these units. Thus, O&M data are limited. The successes exhibited with smaller boilers has started a trend by utilities toward equipping larger plants with fabric filters for particulate emissions control. Some of the O&M experiences reported herein may become less typical as more is learned about the design and operation of fabric filter systems on utility boilers. Several of the references cited herein can be used for further study of U.S. utility O&M experience with fabric filters.

Colorado Springs Department of Public Utilities, Martin Drake 6

Martin Drake 6 is an 85-MW power generating unit located in Colorado Springs, Colorado. The boiler is equipped with a reverse-gas design fabric filter equipped mostly with Teflon B-coated fiberglass bags and a few test bags with acid-resistant coatings. The coal burned at Martin Drake 6 has a heating value of 10,200 Btu/lb and moisture, ash, and sulfur contents of 16, 7.5, and 0.37 percent, respectively. The retrofitted fabric filter system was commissioned into service in 1978.

The system was designed with an air-to-cloth ratio of 2:1 and a flange-to-flange pressure drop of 4 in. H_2O. The unit operates at about 5 inches pressure drop and has recorded a bag replacement rate of about 1 percent (an average of less than one bag per month of a total of 2376 bags). Most failures have occurred between the thimble and the first ring. Some have been attributed to poor installation and others, to weak spots in the bags. The reported areas of concern with regard to bags were the clamping devices and/or procedures used at the thimbles and for bag tensioning.

The utility has experienced problems with temperature instrumentation in that readings become erratic under certain weather conditions. One possible solution was to minimize thermocouple junctions and to extend the wiring all the way to the thermocouple sensor area as much as possible. Whether this was acted upon is unknown. Other reported problems include general bag cleaning problems (accompanied by increased pressure drops), tensioning mechanism problems (such as loss of spring stiffness and ratchet mechanism wear), and loss of pneumatic control (poppet valve operation) due to cold weather freeze-up of control air lines. Also reported were sluggish poppet valve operation on both inlet and outlet, scored cylinders on valve actuators, and shaft seal problems.

In a recent study at this facility, the residual dust cake weight was about 48 lb/bag or 0.5 lb/ft^2. Overall, the fabric filter system operates well. The outlet emission rate is 0.005 to 0.006 lb/10^6 Btu (i.e., a removal efficiency of 99.93%), which is one of the lowest among U.S. installations.

The utility minimizes the potentially serious problems associated with startup by firing natural gas. After the fabric filter has been completely purged with ambient air, it is slowly warmed with the flue gas from the natural gas firing. Four of the system's 12 compartments are brought on line at one time; when the entire system is on line, the boiler is switched to coal-firing.

Kansas City Board of Public Utilities, Kaw 1, 2, and 3

Kaw units 1, 2, and 3 (rated at 44, 44, and 68 MW, respectively) are located in Kansas City, Kansas. All are controlled by reverse-gas fabric filter systems. The systems on Units 1 and 2 use Teflon B-coated fiberglass bags whereas the system on Unit 3 uses acid-resistant-coated bags. The fuel burned at this station is a bituminous coal with a heating value of 11,000 Btu/lb, a moisture content of 6 to 12 percent, an ash content of 15 percent, and a sulfur content of 5 (max.) percent. Units 1 and 2 were commissioned into service in 1979; Unit 3 began operation in 1980.

The Kaw fabric filters were designed with air-to-cloth ratios of approximately 2:1 and flange-to-flange pressure drops of 4 to 6 in. H_2O; however, actual pressure drops fall in the range of 8 to 12 inches, with the average at the higher end of the range. The high pressure drop is attributed, in part, to the boiler operations. Occasionally, the boiler has operated in such a way that the temperature of the gas ducted to the fabric filter has fallen below dewpoint for extended periods. The resulting moist ash accumulation on the bags reduces bag cleaning effectiveness and yields a high pressure drop.

Kaw 1 and 2 each experienced about six bag failures per month (1981), whereas Unit 3 had only three per year. Although bag failures occurred randomly with respect to bag location, the typical failure was at the rings on the lower half of the bag itself. Part of the problem at Kaw 1 and 2 is that the boilers operate in a cycling load; they are not used continuously. Although subject to a fluctuating load, Kaw 3 is rarely shut down completely. Heavier-grade bags (13 oz.) have since been installed with some success at Kaw 1 and 2 to minimize the problem. Fan vibration and overall balance also created some problems, partially because the fans were undersized and partially because of erosion. This could have had an impact on the bag life. The low-horsepower fan problem was solved by installing larger capacity units.

Other than the high pressure drop, the primary problem that the utility reported on Kaw 1 and 2 systems was with reverse-gas fan and fan motor bearing failures. Both units were designed for removal efficiencies of 99.86 percent, but efforts to achieve this design efficiency have been unsuccessful. The units have been unable to achieve the design particulate removal efficiencies. Actual removal efficiencies have been 98.4 percent on Kaw 1 and 98.83 percent on Kaw 2; outlet dust concentrations have been 0.087 and 0.06 lb/10^6 Btu, respectively. This lower removal efficiency is believed to result from the boiler being a cyclic unit burning a high-sulfur coal with a history of low flue gas temperatures and from the high pressure drop of the fabric filter. The removal efficiency of Kaw 1 is one of the lowest recorded among U.S. utility fabric filters.

Minnesota Power and Light, Clay Boswell 1 and 2

The two 69-MW Clay Boswell power generating units in Cohasset, Minnesota are owned and operated by Minnesota Power and Light. The fabric filters on these units are of the reverse-gas design and the bags are woven fiberglass with Teflon B coating. The boilers burn an 8500-Btu/lb subbituminous coal that has moisture, ash, and sulfur contents of 25, 10, and 1 percent, respectively. The units began operations in 1979.

The fabric filters were designed with an air-to-cloth ratio of 2.26:1 and a flange-to-flange pressure drop of 6 in. H_2O. The design particulate removal efficiency is 99.7 percent. Actual pressure drop is 7 in. H_2O and typical particulate removal efficiency is 99.8 percent.

Individual bag failures do not appear to be a major problem at most utility installations--one or two bags per month. At Clay Boswell, however, several hundred bags had to be replaced in one instance as a result of poor bag tensioning. In 1980, bag failures totaled 100 per year; more recently the failure has been about six per month. The bag failures usually occur in the lower 8 feet of the bag. Problems related to boiler tube leaks and low winter boiler loads in some instances have caused flue gas temperature to drop below dewpoint for extended periods. The resulting moist ash accumulation on the bags reduced bag cleaning effectiveness and caused a high pressure drop. When boiler tube leaks were repaired, the problem was eventually brought under control, and the pressure drop fell back down to 7 in. H_2O. Operator experience appears to have been more instrumental in solving the pressure drop problem than anything else. High bag failure rate is still a problem, but no agreement has been reached as to the cause. Flue gas moisture, SO_3, or a combination of the two in conjunction with the plant's start-up/shutdown procedures have been suggested as possible causes. The newer Teflon-core fiberglass bags (used for the past 2 years) have shown a moderate impoundment in bag life.

Initially, several problems were encountered at the Clay Boswell installations. For example, the units originally failed to meet the design requirements of 0.01 grain/scf. After the tube sheet thimbles were seal-welded and pinhole leaks in the bags were repaired, however, an outlet concentration of 0.007 grain/acf was achieved, which is better than the design requirement. The utility reported load reductions of 200 hours in 1979 and 250 hours in 1980 due to fabric filter problems.

Reverse-gas fan and fan motor bearing failures also occurred. According to the log kept on these problems, sluggish poppet valve operation was encountered on both the inlet and outlet, cylinders on valve actuators were scored, and shaft seal problems were noted. In addition, a loss of pneumatic control (poppet valve operation) resulted from a cold weather freeze-up of control air lines. Bag tensioning mechanism problems also occurred, such as loss of spring stiffness and ratchet mechanism wear. The excessive bag failure mentioned earlier was a direct result of poor bag tensioning that allowed the bags to droop, which caused creases and wear points.

Finally, problems with the ash handling system were also reported. Erosion and plugging problems occurred in the vacuum blowers as a result of ash carryover in the transport.

None of the problems encountered at the Clay Boswell facility proved to be critical, and operations have improved considerably since startup.

Nebraska Public Power District, Kramer 1, 2, 3, and 4

Units 1, 2, and 3 at the Kramer Power Station in Bellevue, Nebraska, are rated at 23 MW each; Unit 4 is rated at 36 MW. All the units were started up in 1977, beginning with Unit 1 in March, and all four were on line by May of that year. These units represent the first utility fabric filters used at a plant burning a typical, low-sulfur, Western subbituminous coal in a pulverized coal-fired boiler. The Wyoming subbituminous coal burned at this plant has a heating value of 10,100 Btu/lb, and moisture, ash, and sulfur contents of 21, 3.1, and 0.57 percent, respectively. The fabric filter systems are of reverse-gas design and use typical woven fiberglass bags coated with Teflon B.

The fabric filters were designed with normal air-to-cloth ratios of about 2:1 (2.1:1 for Units 1 through 3 and 1.91:1 for Unit 4) and flange-to-flange pressure drops of about 3 to 5 in. of H_2O. Design particulate removal efficiency of these systems is 99 percent. The units actually have achieved particulate collection efficiencies of 99.9 percent, outlet emissions of 0.002 lb/10^6 Btu, opacities of 0.07 percent, and average pressure drops of 4.5 in. H_2O. The fabric filters on the Kramer units have achieved among the lowest dust emission concentrations (typically 0.005 to 0.006 lb/10^6 Btu) of any U.S. utility fabric filter.

A systematic study of the fabric filter cleaning cycle conducted at Kramer by Electric Power Research Institute (EPRI) investigators and plant personnel established for the first time (in commercial operation) that lengthening the dwell time (time during which no cleaning is taking place in any compartment) decreases emissions without affecting average pressure drop. Further, under some operating conditions, average pressure drop actually decreases with increased dwell time. Substituting a 100-minute cleaning cycle (10-minute dwell time) in place of a 10-minute cleaning cycle (no dwell time) at Kramer reduced particulate matter penetration 50 percent without increasing the pressure drop. Secondary benefits of less frequent bag cleaning are reduced stress on the bags, increased equipment reliability, and a lower average air-to-cloth ratio (as each compartment's time in service versus time out of service during cleaning was increased).

Bag life exceeds 3 years on the Kramer units. Three of the fabric filter systems have 10 compartments each; the fourth has 16. Each compartment has 72 bags, for a total of 3312 bags. The bag tension is 50 lb. Total bag failures by year were 1 in 1977, 12 in 1978, 28 in 1979, 43 in 1980, and 12 in 1981. An additional 18 test bags failed, which were not included in the above figures. During the study period, tests were performed with bags coated with dolomitic lime. As a result, the fabric on Unit 1 experienced fabric blinding and a pressure drop of more than 10 in. H_2O. Fly ash coating was used thereafter. The bag failures were random with respect to bag location in the baghouse, even though the gas distribution is not even across the compartments.

Other problems have included bearing failures and bent shafts on the reverse-gas fans and higher-than-design pressure drops. The latter has not been a big problem, however, because the fans were designed for redundancy.

For boiler startup, the utility has a purge-preheat option. Mechanical collectors are used along with the fabric filters at boiler startup. First, gas is fired, and then coal; when the outlet temperature reaches 300°F, the full gas load is ducted to the fabric filter, and the mechanical collectors, which were operating parallel to the fabric filter up to this point, are closed off. Lower power demands in the recent past have necessitated some cycling of the boilers, and the fabric filters have experienced dewpoint conditions during these periods. As yet no problems have been reported as a result of this cycling; overall the utility is satisfied with the performance of the fabric filters.

Otter Tail Power Co., Coyote 1

Coyote 1 is a 410-MW unit located in Beulah, North Dakota. The boiler is equipped with a sodium-based spray-dryer FGD system followed by a shake-deflate design fabric filter. The bags are made of uncoated synthetics (predominantly acrylic fabric). The coal burned at Coyote is a 7050-Btu/lb Dakota lignite with moisture, ash, and sulfur contents of 36, 7, and 0.78 percent, respectively. The unit began operations in mid-1981.

The design air-to-cloth (A/C) ratio of the fabric filter is 2.5:1, the design flange-to-flange pressure drop is 3 to 5 in. H_2O, and the design particulate removal efficiency is 99.5 percent. The actual air-to-cloth ratio, pressure drop, and removal efficiency were reported to be 3:1, 5 in. H_2O, and 99.53 percent, respectively.

During operation, the flue gas exits two air heaters and flows into a two-stage flue gas cleaning system for removal of SO_2 and particulate. This system consists of four 46-foot-diameter spray dryers that use a sodium carbonate additive as the SO_2 absorbent followed by a 38-compartment fabric filter. Two axial-flow induced-draft fans discharge the filtered flue gas to a single stack. The flue gas temperature at the inlet to the fabric filter is in the range of 210° to 220°F. If flue gas temperatures exceed a predetermined setpoint (well within the fabrics capabilities), an alarm is activated and gas flow is diverted through a fabric filter bypass system. Although fabric air-to-cloth ratios (i.e., gas flows) have been higher than anticipated because the boiler uses more excess air than anticipated in the fabric filter design, the fabric filter has consistently operated well within expectations. The flue gas flow is also greater because the gas exits the boiler at a temperature of about 25°F greater than design, which yields a greater gas volume. Filtration performance (pressure drop, cleanability, and efficiency) has remained relatively stable in spite of a wide variety of boiler and spray dryer system operating conditions. Pressure excursions due to boiler load swings, uneven gas distribution from spray dryers, fabric filter control, equipment malfunctions, etc., have only been temporary, and when the system operation returned to normal, so did pressure drop of the fabric filter.

As would be expected, the higher temperature operation (230° to 250°F compared with the design temperature of 180°F for much of the first 12 months) resulted in discoloration of the acrylic fabric, but had no serious effect on fabric strength, expected service life, or dimensional stability. The higher temperature did accelerate the failure of the polyester fabrics and led to their replacement with the acrylic material. The utility reported it expects to do further testing of polyester fabric (at stable operation with temperatures in the 190° to 220°F range) sometime in the future.

Operating and maintenance details were not available on this system. During the first year-and-a-half of operation the fabric filter underwent a bag material testing program; therefore, bag replacement rates may not be meaningful in this case. Reportedly, however, the installation has exhibited superior performance in terms of low pressure drop at high filter velocities, fabric replacement experience, and service life expectancy.

Pennsylvania Power and Light, Brunner Island 1

Brunner Island 1 is a 350-MW pulverized-coal-fired unit located in Yorkhaven, Pennsylvania. The boiler is equipped with a reverse-gas fabric filter. The bags are made of woven fiberglass with a Teflon coating. Brunner Island 1 burns an 11,000- to 13,000-Btu/lb eastern bituminous coal with a moisture content of 5 to 20 percent, an ash content of 12 to 18 percent, and a sulfur content of 1.1 to 3.0 percent. The unit began operating in October 1980.

The design air-to-cloth ratio is 2.01:1 with two compartments out of service and 2.21:1 with six compartments out of service. The design pressure drop is 6 in. H_2O, and the design particulate matter removal efficiency is 99.9 percent. The fabric filter system actually operates with a normal pressure drop of only 4 in. H_2O. The actual outlet emissions generated during two tests were 0.037 and 0.096 lb/10^6 Btu vs. the design emission rate of 0.075 lb/10^6 Btu. Brunner Island has 24 compartments, with 264 bags per compartment. The utility reported a total of 6 bag failures in 1980 (the unit didn't begin operations until October), 209 failures in 1981, and 877 in 1982 (through early December). The large number of failures adversely affected the pressure drop because of the frequent need to cool compartments for maintenance purposes. The failures occurred randomly throughout the system with respect to bag location. The failures of the bags themselves typically occurred between the thimble and the first ring, and many resulted from bag cuffing. The tension method caused most of the bags either to be overtensioned or undertensioned. The utility solved the tensioning problem by replacing the old stiffer springs with new ones that have superior characteristics. With the old springs, when the bags were ratcheted up a link, they would be either too tight or too loose and no way was provided to adjust the tension between the links. The new springs (although very strong) have better elastic characteristics for this application and yield a more uniform force on the bags from one link to the next. This factor combined with ineffective cleaning of the bags resulted in excessive residual dust cakes. The typical weight of the residual cake on these bags was found to be 1.18 lb/ft^2 or 126 lb per bag.

Problems reported at this facility include those associated with valves (and valve operators), the control system, and tensioning mechanisms. Boiler problems such as tube leaks and operating equipment failures have also added to the problems, as a significant number of load reductions and forced outages have been reported.

Although many aspects of the Brunner Island fabric filter operation were initially discouraging, significant improvements have been made lately. Bag filter total pressure drop, which previously was as high as 12 in. H_2O with all compartments but one in service (one out for bag cleaning), has dropped to approximately 6 in. H_2O at full load with three compartments out of service for maintenance and one for bag cleaning. The utility installed horns for sonic cleaning (eight per compartment) and has been testing several rebagging strategies (warp in/out, new fabric, etc). Although the bags are still not satisfactory, the fabric filter operations at the facility have been relatively reliable.

Pennsylvania Power and Light, Sunbury 1 and 2

The Sunbury units 1 and 2 are located in Shamokin Dam, Pennsylvania. This station marked the first full-scale fabric filter installation at a coal-fired generating plant. The combined capacity of the boilers is about 175 MW. Each of the four boilers is controlled by a fabric filter. The coal blend is 65 to 85 percent anthracite and 15 to 35 percent petroleum coke and bituminous coal. The heating value of this blended fuel is about 9800 Btu/lb. The moisture content is 10 to 20 percent, the ash content is 18 to 30 percent, and the sulfur content is 1.1 to 1.3 percent.

Preceded by modified mechanical collectors that are approximately 70 percent effective in removing particulate matter, these reverse-gas fabric filters at Sunbury have a design air-to-cloth ratio of 2.07:1. The bags are made of woven fiberglass and have a 10 percent by weight Teflon finish. In operation, the units have demonstrated a particulate matter removal efficiency of 99.9 percent versus a design removal efficiency of 99.2 percent. Outlet emissions of 0.005 lb/10^6 Btu were reported, which is among the lowest reported for U.S. utility fabric filters. The plant reportedly shows no visible plume, and the average pressure drop has been as low as 3 in. H_2O versus a design pressure drop of 5 in. H_2O.

A 4-year bag life is reported at the Sunbury station, the longest at any U.S. utility installation. The annual bag failure rate is reported to be 4 percent. The residual dust cake weight recorded in a recent study was 0.72 lb/ft^2 per bag, or about 68 lb/bag per day.[12]

Recently, however, concern arose concerning the performance of the fabric filters when the average flange-to-flange pressure drop rose to about 6 to 6.5 in. H_2O. Although this is cause for concern, the utility has indicated that this is not excessive compared with the pressure drop at other installations.

Overall, Pennsylvania Power and Light is satisfied with the installation. Several factors are believed to have contributed to the generally good performance of the Sunbury fabric filters. First, the boilers typically operate at full load, with minimal swings and unit outages. Second, the bag tensioning system at Sunbury permits tensioning at very nearly a steady 50 lb, whereas at other installations tensioning may be 50 ± 20 lb. Other contributing factors are the use of filter bags that perform well in this specific environment, a relatively low inlet grain loading, and special gas inlet/outlet design features. Unlike most fabric filter installations, the flue gas enters and exits the filter chamber from the center. In typical installations, the gas enters from the side and exits from the side, and pressure drops of the bags closest to the inlet may differ as much as an inch from those of the bags farthest away. Both the quantity and quality of the ash collected differ in those two areas. This does not occur at Sunburry where the more uniform environment is believed to have a beneficial effect on overall bag life and performance.

Sierra Pacific Power Co., North Valmy 1

North Valmy 1 is a 250-MW power generating station located in North Valmy, Nevada. The boiler is equipped with a reverse-gas fabric filter in which Teflon-coated woven fiberglass bags are used. The fuel burned at North Valmy 1 is generally a Western low-sulfur coal. The coal originates from different sources, which accounts for the wide variability of its characteristics. The heating value ranges from 8000 to 12,250 Btu/lb, and it may have a moisture content of 3 to 22 percent, an ash content of 3 to 20 percent, and a sulfur content of 0.3 to 1.5 percent. The unit was commissioned into service in 1981.

The design air-to-cloth ratio of the fabric filter is 1.99:1 (worst coal), and the design flange-to-flange pressure drop is 5.5 in. H_2O. The system contains a total of 6480 bags in 10 compartments. The unit is designed for normal operation with eight compartments--one out for cleaning and one for maintenance. The supplier recommends and the utility practices filter bag precoating. This coating (fly ash) is applied by slowly placing the system in service one compartment at a time after 100 percent coal firing has been achieved.

As of mid-1983, the fabric filter reportedly had not limited boiler operations. Plant operating procedures contribute to the low bag failure rate (less than 0.25 percent versus a contract guarantee of 5 percent maximum failure rate). During the period November 1981 through February 1983, a total of 24 bags failed.

General problems reported for this installation included those associated with valve operation and cold weather. The pneumatic control system was sometimes subject to temperatures as low as 40°F below zero. Water that accumulates in the lines would freeze and general moisture/temperature-related problems caused sluggish operations in equipment throughout the installation because the pneumatic control system was not designed for this environment. The utility reported that injecting alcohol in the lines has reduced the incidence of freeze-up. Casing and door seal leaking accounted for some corrosion. Also, unrelated ductwork corrosion and expansion joint failures have occurred.

On startup, the Nevada Division of Environmental Protection (NDEP) permits Sierra Pacific to wait until the unit is at approximately half-load (125 MW), on two pulverizers, before placing the fabric filter in service. This assures that basically no oil firing is still taking place. This procedure is based on data developed by the supplier, which strongly suggests that the bag life will be seriously reduced if oil soot is allowed to accumulate on the bags, as would occur during a startup. Sierra Pacific believes this procedure has greatly contributed to longer bag life.

During a normal unit shutdown, the fabric filter system is kept in service until the unit is taken off line. The system remains in service for 3 minutes, which allows a hot-air purge of the unit to take place. After the purge, the unit is suited to the "bypass" mode of operation.

If the outage is to be relatively long (several days), the doors are opened and the unit's ventilation system is placed in service. If the outage is expected to be brief, the fabric filter is kept sealed in an effort to reduce moisture infiltration and heat losses.

The utility is generally satisfied with the performance of the fabric filter. Except during bag failures, the system continually maintains its design particulate removal efficiency of 99.7 percent. Opacity readings typically run 2 to 4 percent; during excursions (bag ruptures) the opacity readings rise to the 8 to 10 percent range.

Southwestern Public Service Co., Harrington 2 and 3

Harrington units 2 and 3 are located in Amarillo, Texas. Each is rated at 350-MW. The fabric filter system on Harrington 2 was the first large unit installed on a new utility boiler. The fabric filters on both units are of the shake-deflate design. Originally equipped with silicon/graphite-coated woven fiberglass bags, these units were later switched to Teflon B woven fiberglass bags. The units are fired with an 8230 Btu/lb Western subbituminous coal with moisture, ash, and sulfur contents of 30, 6.4, and 0.48 percent, respectively. Harrington 2 began operations in mid-1978, and Harrington 3 started up in 1980. The design air-to-cloth ratio of the fabric filter on

Unit 2 is 3.4:1, and the design pressure drop is 6 in. H_2O. The design air-to-cloth ratio for the Number 3 unit is 3.0:1, and the design pressure drop is 7 in. H_2O. Actual pressure drop on this unit is 6 in. H_2O. Pressure drops on both units have reached as high as 13 in. H_2O. The pressure drop now is kept below 10 inches, primarily as a result of studies the utility has performed to optimize bag shaking and overall cleaning cycles. The actual particulate removal efficiency for both units is reported to be 99.7 percent for these units with outlet emission concentrations of 0.02 $lb/10^6$ Btu.

The Harrington facility has hosted fabric filter studies on bag fabrics, effects of shaking frequency on pressure drop, and other subjects of concern. As a result of such studies, more suitable bags were identified (the utility now uses 10-oz Teflon-coated fiberglass or 14-oz Teflon- or acid resistant-coated fiberglass bags, the frequency of shaking was increased, and the shaker support mechanism was redesigned. The studies demonstrated the viability of using shake-deflate fabric filters for large-scale installations.

No fabric-filter-related problems have been reported during startup. The startup procedure at Harrington begins with gas firing to bring the boiler outlet gas temperature to about 250°F. The fabric filter is then heated, and when fully on line, the boiler fuel source is switched to coal. The utility has reported no problems traceable to startup or shutdown at Harrington.

Southwestern Public Service Co. is generally satisfied with the operations of the Harrington fabric filters. The utility would like to see improvements made in bag life. Its experience has been 3 to 3.5 years on the best bags. Some studies seem to imply that increasing the filtering time before cleaning could extend the bag life an additional year.

Texas Utilities Co., Monticello 1 and 2

The Monticello steam electric station is located in Mt. Pleasant, Texas. Units 1 and 2 are each rated at 575 MW. The boilers are controlled by fabric filters of the shake-deflate design and parallel electrostatic precipitators. The filter bags are Teflon B-coated woven fiberglass. The coal burned at Monticello is a 5750- to 8000-Btu/lb Texas lignite with a moisture content of 26 to 37 percent, an ash content of 5.8 to 23 percent, and a sulfur content of 0.3 to 2.03 percent. The units were commissioned in 1978 and 1979.

Each of the retrofitted fabric filter systems has a design ratio of 2.9:1 and a flange-to-flange pressure drop of 9 in. H_2O. The actual pressure drop has ranged from 9 to 11 in. H_2O, but recently was reported to be 12 inches. The utility reported that the pressure drop is a function of ash loading and the nature of the fabric filter system. The units now operate in the 10- to 12-inch range. The facility is kept below 12 inches through careful attention to the bag cleaning operations. The residual dust cake weight was measured at 0.33 lb/ft^2 or about 33 lb per bag. Opacity readings range from about 4 to 20 percent.

The utility originally used fiberglass bags coated with a silicon-graphite material, but massive failures occurred after only 4 to 6 months of operation. The primary cause of the bag failures was bag tensioning and subsequent weave tightening; it was impossible to maintain the proper bag tension. These bags accumulated as much as 100 lb of residual ash. Later, the Teflon B-coated fiberglass bags were installed, and many of these have lasted more than 2 years.

The fabric filters were originally designed to control about 80 percent of the gas flow, and the parallel electrostatic precipitators were to control the other 20 percent. Because of problems associated with having these two control devices in parallel, dedicated fabric filter fans had to be installed to maintain the gas flow to these systems.

Pressure drop and relatively short bag life are the two primary concerns voiced by the utility because of the substantial costs associated with these problems. Each fabric filter contains 7344 bags; one unit has been completely rebagged twice, the other has been rebagged once. The utility believes, however, that the 2-year bag life achieved only on the best bags in the past has now become the expected bag life overall.

Recently, the utility has achieved pressure drops as low as 10 to 10.5 in. H_2O on the fabric filters, but no further improvements have been noted since then. The inlet grain loading on these fabric filters is relatively high (9 to 10 grains/acf), and the 12-inch pressure drop mentioned earlier is one of the highest ever reported for any U.S. utility fabric filter installation.

Other general problems reported have included casing and door seal leaking, which resulted in corrosion and flue gas distribution problems. Although the poor gas distribution has not caused serious O&M problems, heavier ash loading has been noted in the hoppers beneath some compartments, which is not expected because the inlet ducts have gas distribution devices built into them. Failures of the reverse gas fans and fan motors have also been noted, and pressure blower erosion in the ash handling system has resulted from ash entrainment in the incoming air stream. These problems are controlled through operation and maintenance measures rather than major design modifications. Some indications of improved availability are evident for the Monticello units. Reported restricted hours for these units are as follows: 740 in 1978, 144 in 1979, and 22 in 1980.

REFERENCES

1. Carr, R. C., and W. B. Smith. Fabric Filter Technology for Utility Coal-Fired Power Plants. J. of the Air Pollution Control Association, 31(2):178-181, 1984.

2. Perkins, R. P. Industrial Fabric Filter Experience Applicable to Utilities. In Proceedings of First Conference on Fabric Filter Technology for Coal-Fired Power Plants, Denver Colorado, July 15-17, 1981. CS-2238. p. 3-37.

3. U.S. Department of Energy. Inventory of Power Plants in the United States. Office of Utility Project Operations. DOE/RA-0001, December 1977.

4. U.S. Department of Energy. Inventory of Power Plants in the United States - December 1979. Energy Information Administration. DOE/EIA-0095(79), June 1980.

5. U.S. Department of Energy. Inventory of Power Plants in the United States - 1980 Annual. Energy Information Administration. DOE/EIA-0095(80), June 1981.

6. U.S. Department of Energy. Inventory of Power Plants in the United States - 1981 Annual. Energy Information Administration Office of Coal, Nuclear, Electric, and Alternate Fuels. DOE/EIA-0095(81), September 1982.

7. Personal communication from Mr. Skeer, Office of Policy Planning and Analysis, U.S. Department of Energy, August 1983.

8. Piulle, W., and R. Carr. Operating History and Current Status of Fabric Filters in the Utility Industry. In Proceedings of First Conference on Fabric Filter Technology for Coal-Fired Power Plants, Denver, Colorado, July 15-17, 1981. CS-2238. p. 1-5.

9. Piulle, W., and R. Carr. 1983 Update, Operating History and Current Status of Fabric Filters in the Utility Industry. In: Proceedings of Second Conference on Fabric Filter Technology for Coal-Fired Power Plants Denver, Colorado, March 22-24, 1983. EPRI CS-3257. p. 1-5.

10. Carr, R. C., and W. B. Smith. Fabric Filter Technology for Utility Coal-Fired Power Plants. J. of the Air Pollution Control Association 31(2) and 31(3), 1984.

REFERENCES

11. Electrical Power Research Institute (EPRI). Proceedings of First Conference on Fabric Filter Technology for Coal-Fired Power Plants. EPRI CS-2238, February 1982.

12. EPRI. Proceedings of Second Conference on Fabric Filter Technology for Coal-Fired Power Plants. EPRI CS-3257, November 1983.

GLOSSARY OF TERMINOLOGY[1]

ABRASION - FLEX: Where the cloth has abraded in a creased area by repeated bending.

ABRASION - SURFACE: Where the cloth surface has been abraded by rubbing, scuffing, erosion.

ABSOLUTE ZERO: The zero from which absolute temperature is reckoned. Minus 460°F., approximately.

ACETATE: A manufactured fiber in which the fiber forming substance is cellulose acetate.

ACRYLIC: A man-made polymerized fiber which contains at least 85% acrylonitrile.

AEROSOL: An assemblage of small particles, solid or liquid, suspended in air or gas.

AIR, DRY: In psychrometry, air containing no water vapor.

AIR, STANDARD: Air with a density of 0.075 lb. per cubic foot. This is substantially equivalent to dry air at 70°F. and 29.92 in. (Hg) barometer.

AIR-TO-CLOTH RATIO: The volumetric rate of capacity of a fabric filter; the volume of air (gas) cubic feet per minute, per square foot of filter media (fabric).

ANEMOMETER: An instrument for measuring the velocity of air or gas.

ATMOSPHERIC PRESSURE: The pressure of the atmosphere as measured by means of the barometer at the location specified.

BACKWASH: A method of fabric cleaning where direction of filter flow is reversed, accompanied by flexing of the fabric and breaking of the dust cake. Also known as backpressure, repressure, collapse-clean, etc.

BAG: The customary form of filter element. Also known as tube, stocking, etc. Can be unsupported (dust on inside) or used on the outside of a grid support (dust on the outside).

BATCH CLEANED: Usually refers to a process used in heat cleaning fiber glass cloth in roll form by exposing it at 500°F. to 600°F. for prolonged periods to burn off the starches or binders.

BLAST GATE: A sliding plate installed in a supply or exhaust duct at right angles to the duct for the purpose of regulating air flow.

BLINDING (BLINDED): The loading, or accumulation, of filter cake to the point where capacity rate is diminished. Also termed "plugged".

BRITISH THERMAL UNIT (btu): The amount of heat required to raise one pound of water one degree fahrenheit.

BROKEN TWILL: Modified twill weave where the diagonal twill line is shifted in a regular pattern.

BULKED YARN: Multi-filament yarn which has been processed by high pressure air passing through the yarn and relaxing it into gentle loops, bends, etc.

CALENDERING: The application of either hot or cold pressure rolls to smooth or polish a fabric, thereby reducing the thickness of the cloth and decreasing air permeability.

CANTON FLANNEL: Usually a twill weave fabric with the filling float heavily napped.

CHAIN WEAVE: A 2/2 broken twill weave, arranged 2 threads right and 2 left.

CLOTH: In general, a pliant fabric; - woven, knitted, felted, or otherwise formed of any textile fiber, wire, or other suitable material. Usually understood to mean a woven textile fabric.

CLOTH WEIGHT: Is usually expressed in ounces per square yard or ounces per square foot. However, cotton sateen is often specified at a certain number of linear yards per pound of designated width. For example, a 54" - 1.05 sateen weighs 1.05 linear yards per pound in a 54" width.

CONDENSATION: The process of changing a vapor into liquid by the extraction of heat.

CORONIZING: A heat cleaning process for fiber glass fabric to burn off the starches (used in processing) usually at temperatures of 1000°F. for short duration.

CORROSION: Deterioration or physical degredation due to chemical action.

COTTON NUMBER: Staple yarns are generally sized on the cotton system. Example: an 18 singles yarn is of such size that 18 hanks (each hank contains 840 yards) weighs one pound.

COUNT: The number of warp yarns (ends) and filling yarns (picks) per inch. Also called thread count.

COVER: A description term for the appearance of woven goods. A well covered cloth is the opposite of an open, or "reedy" cloth.

CRIMP: The corrugations in a yarn from passing over and under other yarns at right angles.

CROWFOOT SATIN: A 3/1 broken twill arranged 2 threads right, then 2 threads left, etc. Also called 4 shaft satin, or broken crow weave.

DAMPER: An adjustable plate installed in a duct for the purpose of regulating air flow.

DEHUMIDIFY: To reduce by any process the quantity of water vapor.

DENIER: The number, in grams, of a quantity of yarn, measuring 9000 meters in length. Example: A 200 denier yarn measuring 9000 meters weighs 200 grams. A 200/80 yarn indicates a 200 denier yarn composed of 80 filaments. Usually used for continuous multi-filament yarns of silk, rayon, Orlon,® Dacron,® Dynel,® Nylon,® etc.

DENSITY: The ratio of the mass of a specimen of a substance to the volume of the specimen. The mass of a unit volume of a substance. Dry air at 70°F. and 29.92" Hg has a density of 0.075 pounds per cubic foot.

DIMENSIONAL STABILITY: Ability of the fabric to retain finished length and width, under stress, in hot or moist atmosphere.

DRILL: Same as twill except the diagonal twill line usually runs from lower right to upper left. A 2/1 LH twill, or 3/1 twill.

DUST: Solid particles less than 100 microns created by the attrition of larger particles. Particles thus formed are not usually called dust unless they are larger than about 1 micron diameter.

DUST COLLECTOR: A device to remove solid aerosol particles from a gas stream.

DUST LOADING: The weight of solid particulate suspended in an air (gas) stream, usually expressed in terms of grains per cubic foot, grams per cubic meter or pounds per thousand pounds of gas.

DUST PERMEABILITY: Defined as the mass of dust (grains) per square foot of media divided by the resistance (pressure drop) inches w.g. per unit of filtering velocity, fpm. Not to be compared with cloth permeability.

END: An individual yarn or cord; a warp yarn running lengthwise of the fabric.

ENTRY LOSS: Loss in total pressure caused by air (gas), flowing into a duct or hood (usually expressed in inches w.g.).

ENVELOPE: A common form of filter element.

EROSION: Wearing away due to mechanical action.

EXTENSIBLILITY: The stretching characteristic of fabric under specific conditions of load, etc.

FABRIC: A planar structure produced by interlacing yarns, fibers or filaments.

KNITTED Fabrics are produced by interlooping strands of yarn, etc.

WOVEN Fabrics are produced by interlacing strands at more or less right angles.

BONDED Fabrics are a web of fibers held together with a cementing medium which does not form a continuous sheet of adhesive material.

FELTED Fabrics are structures built up by the interlocking action of the fibers themselves, without spinning, weaving or knitting.

FIBER: The fundamental unit comprising a textile raw material such as cotton, wool, etc.

FILAMENT: A continuous fiber.

FILL: Crosswise threads woven by loom.

FILL COUNT: Number of fill threads per inch of cloth.

FILLING YARN: Yarns in a fabric running across the width of a fabric; i.e., at right angles to the warp.

FILTER DRAG: Pressure drop, inches w.g. per cubic foot of air per minute, per square foot of filter media. Analogous to the resistance of an element in an electrical circuit. The ratio of filter pressure to filter velocity.

FILTER MEDIA: The substrate support for the filter cake; the fabric upon which the filter cake is built.

FILTER VELOCITY: The velocity, feet per minute, at which the air (gas) passes through the filter media, or rather the velocity of approach to the media. The filter capacity rate.

FILTRATION RATE: The volume of air (gas), cubic feet per minute, passing through one square foot of filter media.

FINISHED: A fabric which has been processed after weaving, i.e., other than in the greige.

FLAME RETARDANT: A finish designed to repel the combustibility of a fabric, either of a durable or non-durable type.

FLOAT: The position of a yarn that passes over two or more yarns passing in the opposite direction. Example: in standard cotton sateen, yarns "float" four, and pass under one. In other words 4/1.

FLUOROCARBON: Fiber formed of long chain carbon molecules, available bonds saturated with fluorine.

FOG: Suspended liquid droplets generated by condensation from the gaseous to the liquid state, or by breaking up a liquid into a dispersed state, such as by splashing, foaming and atomizing. (See mist)

FULLED: A woven fabric treated to raise fiber ends (like napping) so that the thready, woven look is partially or completely obscured.

FUME: Fine particles dispersed in air or gases, formed by condensation, sublimation or chemical reaction. Particles are usually less than one micron in size.

GAS: Gas is a formless state of matter completely occupying any space. Air is a gas.

GLASS (FIBER-GLASS): A manufactured fiber in which the fiber forming substance is glass.

"GRAB" TENSILE: The tensile strength, in pounds per inch, of a textile sample cut 4" x 6" and pulled in two lengthwise by two 1" square clamp jaws set 3" apart and pulled at a constant specified speed.

GRAIN: 1/7000 pound or approximately 65 milligrams.

GRAVITY, SPECIFIC: The ratio of the mass of a unit volume of a substance to the mass of the same volume of a standard substance at a standard temperature. Water is usually taken as a standard substance. For gases, dry air at the same temperature and pressure as the gas is often taken as the standard substance.

GREIGE CLOTH: Cloth as it comes off the loom, or so-called "loom finish".

GRID CLOTH: The cloth used in supporting the sliver in making a supported, needled felt.

HAND OR HANDLE: The "feel" of the cloth - as soft, harsh, smooth, rough, silken-like, boardy, etc.

HARNESS: The frame used to raise or lower those warp yarns necessary to produce a specific weave at the same time permitting the filling to be passed through by the shuttle.

HEAD END: A piece of fabric taken from the end of a roll of cloth.

HEAD SET: A finishing process for that particular fiber, in fabric form, to stabilize it against further shrinkage at predetermined temperatures.

HEAT, SPECIFIC: The heat absorbed (or given up) by a unit mass of a substance when its temperature is increased (or decreased) by one degree. The common unit is the btu per degree Fahrenheit. For gases, both specific heat at constant pressure (c_p) and specific heat at constant volume (c_v) are frequently used.

HOOD SUCTION: The entry loss plus the velocity pressure in the connecting duct.

HUMIDITY, ABSOLUTE: The weight of water vapor carried by a unit weight of dry air or gas. Pounds of water vapor per pound of dry air; grains of water vapor per pound of dry air.

HUMIDITY, RELATIVE: The ratio of the absolute humidity in a gas to the absolute humidity of a saturated gas at the same temperature.

HYDROPHILIC FIBERS: Those fibers not readily water absorbent.

HYGROSCOPIC: Those fibers which are water absorbant.

INCH OF WATER: A unit of pressure equal to the pressure exerted by a column of liquid water one inch high at a standard temperature. The standard temperature is ordinarily taken as 70°F. One inch of water at 70°F. = 5.196 lb per sq. ft.

INTERLACING: The points of contact between the warp and filling yarns in a fabric.

INTERSTICES: The openings between the interlacings of the warp and filling yarns; i.e., the voids.

K FACTOR: The specific resistance of the dust cake, inches water gage per pound of dust per square foot of filter area per feet per minute filtering velocity.

LOOM FINISH: Same as greige cloth.

MANOMETER: An instrument for measuring pressure; a U-tube partially filled with a liquid, usually water, mercury or a light oil, so constructed that the amount of displacment of the liquid indicates the pressure being exerted on the instrument.

MICRON: A unit of length, the thousandth part of 1 mm or the millionth of a meter, (approximately 1/25,000 of an inch).

MILDEW RESIST FINISH: An organic or inorganic finish to repel the growth of fungi on natural fibers.

MIST AND FOG: A distinction sometimes made between mist and fog is of minor importance since both terms are used to indicate the particulate state of airborne liquids. Mist is a visible emission usually formed by a condensation process or a vapor-phase reaction, the liquid particles being sufficiently large to fall of their own weight.

MODACRYLIC: A man-made fiber which contains less than 85% acrylonitrile (at least 35%).

MOL: A weight of a substance numerically equal to its molecular weight. If the weight is in pounds, the unit is "Pound Mol". For dry air at 70°F., and a pressure of one atmosphere, a pound mol occupies 386 cubic feet.

MONOFILAMENT: A continuous fiber of sufficient size to serve as yarn in normal textile operations.

MULLEN BURST: The pressure necessary to rupture a secured fabric specimen, usually expressed in pounds per square inch.

MULTIFILAMENT: (Multifil) A yarn bundle composed of a number of filaments.

NAPPED: A process to raise fiber or filament ends (for better coverage and more surface area) accomplished by passing the cloth over a large revolving cage or drum of small power-driven rolls covered with card clothing (similar to a wire brush).

NEEDLED FELT: A felt made by the placement of loose fiber in a systematic alignment, with barbed needles moving up and down, pushing and pulling the fibers to form an interlocking of adjacent fibers.

NON-WOVEN FELT: A felt made either by needling, matting of fibers or compressed with a bonding agent for permanency.

NYLON: A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polyamide having recurring amide groups.

OLEFIN: A manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85% by weight of ethylene, propylene, or other olefin units.

PERMEABILITY, FABRIC: Measured on Frazier porosity meter, or Gurley permeometer, etc. Not to be confused with dust permeability. The ability of air (gas) to pass through the fabric, expressed in cubic feet of air per minute per square foot of fabric with an 0.5" H_2O pressure differential.

PICK: An individual filling yarn running the width of a woven fabric at right angles to the warp. In England it is termed woof, or weft.

PICK GLASS: A magnifying glass used in counting the warp and filling yarn in the fabric.

PITOT TUBE: A means of measuring velocity pressure. A device consisting of two tubes - one serving to measure the total or impact pressure existing in an air stream, the other to measure the static pressure only. When both tubes are connected across a differential pressure measuring device, the static pressure is compensated automatically and the velocity pressure only is registered.

PLAIN WEAVE: Each warp yarn passing alternately over each filling yarn. The simplest weave, 1/1 construction. Also called taffeta weave.

PLENUM CHAMBER: An air compartment maintained under pressure, and connected to one or more ducts. A pressure equalizing chamber.

PLY: Two or more yarns joined together by twisting.

POLYESTER: A manufactured fiber in which the fiber forming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of dihydric alcohol and terephthalic acid.

POROSITY, FABRIC: Term often used interchangeably with permeability. Actually percentage of voids per unit volume - therefore, the term is improperly used where permeability is intended.

PRESHRUNK: Usually a hot aqueous immersion of the cloth to eliminate its tendency to shrink in further wet performances.

PRESSURE, ATMOSPHERIC: The pressure due to the weight of the atmosphere, as indicated by a barometer. Standard atmospheric pressure is 29.92" of mercury equivalents in other units are 760 mm of mercury, 14.7 psia, and 407 inches water column.

PRESSURE, GAGE: Pressure measured from atmospheric pressure as a base. Gage pressure may be indicated by a manometer which has one leg connected to the pressure source and the other exposed to atmospheric pressure.

PRESSURE JET CLEANING: A bag cleaning method where a momentary burst of compressed air is introduced through a tube or nozzle attached to the top cap of a bag. A bubble of air flows down the bag, causing bag walls to collapse behind it.

PRESSURE, RESISTANCE: Resistance pressure (RP) is the pressure required to overcome the resistance of the system. It includes the resistance of straight runs of pipe, entrance to headers, bends, elbows, orifice loss, and cleaning device. It is indicated by the difference of total pressure between two points in the duct system.

PRESSURE, STATIC: The postential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow. Usually expressed in inches water gage, when dealing with air.

PRESSURE, TOTAL: The algebraic sum of the velocity pressure and the static pressure (with due regard to sign). In gas-handling systems these pressures are usually expressed in inches water gage. The sum of the static pressure and the velocity pressure.

PRESSURE, VELOCITY: The kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. Usually expressed in inches water gage.

PULSE JET: A system of bag cleaning using a momentary burst of compressed air in the discharge nozzle of a filter bag, which stops filter flow and inflates the bag in the opposite direction.

RAVEL STRIP TENSILE: The tensile strength, in pounds per inch of a 6" long textile sample cut just over one inch wide, (with yarns peeled off each side down to exactly one inch wide) pulled in two lengthwise between jaws set 3" apart and pulled at a constant specified speed.

RAYON: A manufactured fiber composed of regenerated cellulose.

REED MARKS: The identations between 2, 3 or 4 ends, usually eliminated in finishing.

REPEAT: The number of threads in a weave before the weave repeats or starts over again. The number of ends and picks in the repeat may be equal or unequal, but in every case the repeat must be in a rectangular form.

RESISTANCE: Analogous to electrical resistance - the pressure drop across the filter media and dust cake, expressed in inches water gage.

REVERSE JET CLEANING: A cleaning method (Hersey) using a traveling ring traversing the exterior of the filter bag. High pressure air is blown backwards through the fabric through small holes or slots in contact with the cloth.

SANFORIZED: A patented process where the cloth is "puckered" in the warp direction to eliminate shrinkage in laundering.

SARAN: Any long-chain synthetic polymer composed of at least 85% vinylidene - chloride units.

SATEEN: Cotton cloth made with a 4/1 satin weave, either as warp sateen or filling sateen.

SATIN WEAVE: A fabric usually characterized by smoothness and luster. Generally made warp face with a great many more ends than picks. The surface consists almost entirely of warp (or filling) floats in construction 4/1 to 7/1. The intersection points do not fall in regular lines, but are shifted in a regular or irregular manner.

SCOUR: A soap and hot water wash to "off loom" fabric.

SELVAGE: The binding lengthwise edge of a woven fabric.

SHAKING (CLEANING): A common, mechanical method of removing dust from filter elements. Backwash, or other supplemental methods, are often used with shaking.

Air-shaking is a bag cleaning means wherein bags are shaken in a random fashion by high velocity air stream rather than by mechanical devices.

SINGEING: The burning off of the protruding hairs from the warp and filling yarns of the fabric.

SINGLES: The term used to imply only one yarn.

SIZING: A protective coating applied to yarn to insure safe handling; i.e., abrasion-resistance during weaving.

SLEAZY: Lacking in firmness or substance; thin, flimsy.

SLIPPAGE: The movement or shifting of yarns in a fabric from their normal position.

SLUB: A heavy accumulation of fiber or lint carried on a yarn and interlocked during weaving.

SMOKE: An air suspension (aerosol) of particles, usually but not necessarily solid, originating from a combustion process.

SONIC (SOUND): A fabric cleaning method using acoustic energy to vibrate the filter elements. Used alone, or as a supplement to shaking, or backwash cleaning.

SPUN FABRIC: Fabric woven from staple (spun) fiber - same as staple.

STANDARD ATMOSPHERE: The pressure exerted by a column of mercury 29.92" high at 70°F approximately 14.7 psi.

STAPLE FIBER: Man-made fibers cut to specific length - 1-1/2", 2", 2-1/4" etc. - natural fibers of a length characteristic of fiber, animal fibers being the longest.

"S" TWIST: The yarn spirals conform in slope to the center portion of the letter "S".

TAFFETA: Closely woven plain weave (1/1) fabrics with the warp yarns greatly outnumbering the filling yarns.

TEMPERATURE, ABSOLUTE: Temperature expressed in degrees above absolute zero.

TEMPERATURE, DEW-POINT: The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 per cent relative humidity) for a given absolute humidity at constant pressure.

TEMPERATURE, DRY-BLUB: The temperature of a gas or mixture of gases indicated by an accurate thermomenter after correction for radiation.

TEMPERATURE SCALES: Temperature scales, Centigrade and Fahrenheit derive their degree values by dividing the difference between the ice point and steam points of water as follows: Centigrade 100 and Fahrenheit 180. The value of a Fahrenheit degree is therefore 5/9 of a Centigrade degree. The Fahrenheit scale is generally used in air handling practice. The Rankine scale, sometimes called Fahrenheit absolute, has its zero at the lowest attainable temperature, exactly 459.67 degrees below the zero of the Fahrenheit scale. To convert Fahrenheit to Rankine temperature (generally designated R), add 459.67 degrees, (460 is sufficiently accurate).

TEMPERATURE, WET-BULB: Wet bulb temperature is a measure of the moisture content of air (gas). It is the temperature indicated by a wet bulb psychrometer.

TENACITY: Ultimate tensile strength of a fiber, filament, yarn, etc. expressed in grams per denier (g.p.d.).

TENSILE STRENGTH: The ability of yarn or fabr to resist breaking by direct tension. Ultimate breaking strength in psi.

TENTER FRAME: (Pin tenter) A machine for drying cloth under tension. Tentering. Also called framing.

TEXTILE: That which is or may be woven. Comes from the Latin "Texere", to weave. Hence any kind of fabric.

THREAD COUNT: The number of ends and picks per inch of a woven cloth. For example 64x60 (ends count first).

THROW: Process of doubling or twisting fibers into a yarn of the desired size and twist.

TOW: A large number of filaments collected in a loose rope-like form, without definite twist.

T.P.I.: Twist per inch. (Turns per inch).

TWILL WEAVE: Warp yarns floating over or under at least two consecutive picks from lower to upper right, with the point of intersection moving one yarn outward and upward or downward on succeeding picks, causing diagonal lines in the cloth.

TWIST: The number of complete spiral turns per inch in a yarn, in a right or left direction; i.e., "S" or "Z" respectively.

VAPOR: The gaseous form of substances which are normally in the solid or liquid state and which can be changed to these states either by increasing the pressure or decreasing the temperature.

VELOCITY HEAD: Same as velocity pressure. (S Pressure, Velocity).

VELOCITY OF APPROACH: The velocity of air (gas), feet per minute, normal to the face of the filter media.

VELOCITY TRAVERSE: A method of determining the average air velocity in a duct. A duct, round or rectangular, is divided into numerous sections of equal area. The velocity is determined in each area and the mean is taken of the sum.

VOLUME, SPECIFIC: The volume of a substance per unit mass; the reciprocal of density; usually given in cubic feet per pound, etc.

WARP: Lengthwise threads in loom or cloth.

WARP BEAM: Large spool-like or barrel-like device on which the warp threads are wound.

WARP COUNT: Number of warp threads per inch of width.

WARP SATEEN: The face of the cloth having the warp yarns floating over the filling yarns and being greater in number than the filling yarns (per inch).

WEAVE: The pattern of weaving; i.e., plain, twill, satin, etc.

WEFT: Same as filling, the crosswise threads (yarns).

WOOF: Same as filling or weft.

WOOLEN SYSTEM: A "system" of yarn manufacturing for spinning wool fiber into yarn, usually more open and not aligned as parallel as the cotton system.

WORSTED SYSTEM: A system of yarn namufacturing suited for medium and longer wools. Includes additional processing steps resulting in the most uniform yarn. The resulting yarn is compact and level.

WOVEN FELT: Predominantly a woven woolen fabric heavily fulled or shrunk with the weave being completely hidden due to the entanglement of the woolen fibers.

YARN: Twisted fibers or filaments in a continuous strand suitable for weaving, etc. Ply yarn is formed by twisting two or more single yarns together. Ply yarns are in turn twisted together to form cord.

YARN SIZE (DENIER, OR COUNT): A relative measure of fineness or coarseness of yarn. The smaller the number in spun yarns, the coarser the yarn. The higher the denier of a filament yarn, the coarser (heavier) the yarn.

"Z" TWIST: The yarn spirals conform in slope to the center portion of the letter "Z".

REFERENCE

1. Industrial Gas Cleaning Institute (IGCI). Fundamentals of Fabric Collectors and Glossary of Terms. Publication F-2. Stamford, Conn. 1972.

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